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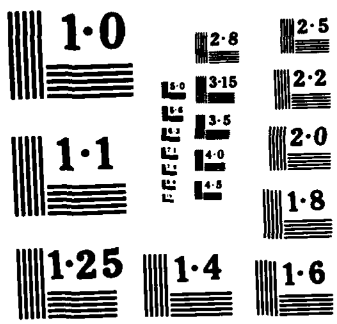

NATIONAL BUREAU OF STANDARDS
MICROCOPY RESOLUTION TEST CHART

AD-A162 884

Report 0162-06-SAAS-35

AGING AND SURVEILLANCE PROGRAM MINUTEMAN II/III STAGE II PROGRAM PROGRESS

Report Period: 15 March 1985 - 31 August 1985

November 1985

Aerojet Strategic Propulsion Company

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AGING AND SURVEILLANCE PROGRAM MINUTEMAN II/III STAGE II PROGRAM PROGRESS

Report Period: 15 March 1985 - 31 August 1985

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QUALITY INSPECTED 3

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I. SUMMARY/RECOMMENDATIONS

A. PROPELLLANT-LINER-INSULATION

Seven motors were tested as part of the ongoing Ignition Delay Program during this reporting period (page 45). Sample variability continues to be a problem; especially on regrain motors. The quality of the propellant surfaces in the fin slots of recent regrain motors has been very poor and is not typical of the released surface in the rest of the motor. Manufacturing is aware of the problem. Improvement of the excise tooling is proceeding cautiously.

Results from nondestructive testing indicate that two motors show a significant deviation from the mean E_o of the washout motors. Motor AA21321 is the early age-out motor and Motor AA20629 is the "cracked" motor. The deviations from the mean for these motors are -35%, and -17.7%, respectively (page 44).

The remanufactured motors show large variance from the mean E_o. Since the motors are usually tested within one month of the cast date, these variations may be a result of propellant changes associated with postcure.

Since the last report period, 31 motors were visually inspected (Page 39). Motor SN AA20629 revealed an 11-in. crack in the nozzle well. The cause of the crack cannnot be attributed to aging. This motor is discussed in Section VI.C.1 of this report (page 73).

Visual inspection of motors by OO-ALC is being included in the database. The data source greatly increases the value of the visual inspection data and should be continued. These data comprise a key portion of the "Early Age-out" material discussed in Section VI.C.2 of this report (page 79).

Significant differences between Phillips and GTR propellants continue to be evident in aging trends for propellant within 1 in. of the bore

I.A. Propellant-Liner-Insulation (Cont)

surface and bondline interface of the motor. Propellant formulated with Phillips CTPB exhibits higher strength and modulus and lower strain capability, and indicates a trend toward continued hardening with age. Strength and strain capability of GTR propellants both tend to decrease with age while modulus shows little change with storage time. All motors now being remanufactured are cast with propellant formulated with Phillips CTPB (page 23).

Data for excised samples removed from the aft end of six field-returned motors tested during the current report period generally support previously established trend lines indicating that (1) a difference in propellant aging trends for Phillips and GTR propellants (page 26), (2) wide variability in properties of insulation with a trend toward hardening with age (page 37), and (3) reduced bond strength resulting from degraded liner (page 33).

An excised sample was removed from Motor AA21321 (aged 138 mo) to evaluate prematurely aged condition of the liner noted at Hill Air Force Base. Data indicate propellant is typical for aged Phillips motors; bond and chemical testing indicate severely degraded liner (page 85).

Plugs have been removed from the forward and aft chamber areas of Motor MSEX-2, 1984 vintage, following 18 mo storage. Bulk propellant exhibits expected hardening due to postcure for both locations. Softening at the bondline, noted in analogs stored 8 mo at 135°F or 16 mo at 110°F, is apparent following 18-mo storage at ambient for plugs from Motor MSEX-2. No reduction in bond strength is evident with additional storage time (page 98).

A propellant crack was identified in a field-returned motor (AA20629, aged 198 mo) during routine nondestructive testing prior to remanufacture. Based on observations under ultraviolet light and scanning electron microscope, the crack probably originated at the time of manufacture. Properties of propellant-liner-insulation samples removed from the motor are typical of aged propellant (page 73).

I.A. Propellant-Liner-Insulation (Cont)

Motor AA22050, 1980 vintage, was dissected at OO-ALC in 1985 (page 109). Preliminary results of testing conducted on sections of the weather-sealed motor indicate the following:

- Good agreement in uniaxial tensile properties of propellant from three locations (forward bore, forward and aft Y-joints

- Presence of a hardened layer at the bore surface (as measured in nonsealed motors)

- Reduced bond tensile strength in the forward and aft boot areas of the motor in comparison with the chamber area. Based on a comparison of data from a non-weathersealed motor of approximately the same age (Motor AA20846, aged 57 mo), bond strength in the forward boot may be improved by the presence of the weatherseal (page 109).

- Based on this initial reduction in properties, it is recommended that remnant testing be accelerated to confirm the trend.

Conclusions from the Early Age-Out program (page 79) can be summarized as follows:

. On the basis of test data and visual inspection reports from ASPC, similar failure mechanisms are responsible for the rejection of Motors AA21049 and AA21321 from operational use. The probable cause of premature age-out conditions, evidenced by excessive boot gap, is related to shrinkage of the boot insulation and to degradation of the liner. The degree of liner degradation is greater in Motor AA21321 compared to Motor AA21049.

. The batch-to-batch variability in bond strength and liner properties observed in Hill Air Force Base carton testing implies that individual batches may be anomalous rather than all batches from an entire liner lot.

I.A. Propellant/Liner/Insulation (Cont)

. The preliminary assessment of the manufacturing variables study indicates that the rate of motor age-out may be predictable from the type of data gathered in motor manufacturing supplemented by existing motor excised sampling data.

B. COMPONENTS

1. Motor Postfire Inspection

No motors were fired during this report period.

2. Nozzle Inspection

Nozzle SN 2168064 was visually inspected and pressure tested during this report period. Testing was non-destructive, and results will create a new database for nozzles being returned from the field (page 135).

3. LITVC and RC Gas Generators

Four TVC and three RC gas generators were successfully fired this report period. Service life of both is beyond 34 years (page 135).

4. LITVC Permeation

TVC Tanks T-159 and T-210 were rebuilt with Uniroyal bladders. Permeation testing began April 1985. Permeation rate plateaus as expected (page 138).

5. LITVC Tank and Components

TVC tanks AAB-0535 and AAB-0469 were cold gas flow tested May and June 1985 (page 140). Curve smoothing was required of system AAB-0535

I.B. Components (Cont)

due to high testing noise. Burst disc burst pressures were within specification for both systems and no aging trends are seen.

6. Igniter Firings

Nineteen igniters, removed from motors returned to ASPC for remanufacture, were fired in August and September for VECP B-177 (page 125). Preliminary analyses show no aging trends. Because of a testing difference from Lot Acceptance tests and/or a possibility of igniter contamination, some igniters showed high ignition delays. Further testing and analysis will be done to resolve the questions of testing difference and contamination.

Two aging and surveillance igniters were also scheduled for test during this report period, but testing was delayed pending a thorough evaluation of the nineteen VECP B-177 igniter test results. The two aging and surveillance igniters will be fired during the next report period, and results from these firings, as well as the VECP firings, will be reported in SAAS-36.

II. INTRODUCTION

This semiannual report provides results of tests conducted between 15 March 1985 and 31 August 1985 in support of the Aging and Surveillance program for the Minuteman II and III Stage II motors as described in References 1 through 4.* The primary objectives of the program are to provide assurance that (1) the reliability of the presently deployed motor will not degrade within a projected replacement time of 17 years, and (2) the service life of the remanufactured motor will be equal to or greater than that of the presently deployed motor population.

To simplify both analysis and presentation of ever-increasing aging data, information from similar materials has been combined; remnants, excised samples, and bulk samples from aged motors are treated as a population of materials from motors. Because a motor/carton bias has been identified, data from laboratory samples will be analyzed independently.

Detailed tabulations for samples tested during the report period are presented in Appendices A through C.

This volume also summarizes results of work completed in a number of special areas. Topics include initial testing of plug samples from a late production motor, dissection of a weathersealed motor, investigation of a propellant crack in a field-returned motor, investigation of early age-out motors, and evaluation of Stage II igniters for re-use in remanufactured motors. Because of the specialized nature of these topics, particular attention will be devoted to each topic separately in Section VI.C. Where applicable, test results have been incorporated into the Aging and Surveillance database for evaluation with comparable data.

* A reference list is included at the end of the text.

III. BACKGROUND

A failure mode involving degradation of SD-851-2 liner was demonstrated during the Minuteman Long Range Service Life Analysis (LRSLA) program. On the basis of studies indicating this degree of degradation could be expected in motors ranging in age from 14 to 17 years, a remanufacture program was initiated in 1978.

Special studies have been conducted since that time to investigate two additional possible failure modes of the propellant-liner-insulation system: (a) ignition delay, and (b) grain cracking due to surface hardening of the propellant (References 5 and 6). Although neither study indicated that the present motor replacement schedule (based on degradation of SD-851-2 liner) needed to be accelerated at that time, data are being obtained on a routine basis to monitor both surface hardening and ignition delay as possible age-limiting modes of failure. Results of studies recently conducted to assess effects of low-equilibrium moisture on a weathersealed motor are consistent with nominal service life of 17 years (Reference 7).

A revised test plan, ATF-II-SLA-1 (Reference 8), has been approved by OO-ALC that will emphasize testing of materials representing remanufactured motors. Limited material testing from original-manufacture motors will be continued to provide visibility of long-term aging stability and a base against which performance of the remanufactured motor can be measured.

An extensive program to evaluate the aging stability of motor components other than the propellant-liner-insulation system was conducted prior to transition of the Aging and Surveillance program to OO-ALC in 1972. This program was continued on a limited basis until 1980, when it was revised to support the Minuteman Remanufacture program. Details of current investigations are described in References 2, 4, and 8.

IV. SERVICE LIFE ESTIMATE

Information developed during the Long Range Service Life Analysis program identified hydrolytic liner degradation as the primary mechanism leading to failure for the motor. Kinetic projections for service life ranged from 14 to 17 years based on an assumed silo environment of 50% RH at 70°F. Silo conditions were known to vary, however, and installation of weatherseals in Minuteman motors was recommended to eliminate the effects of extreme humidity conditions in the silos. Subsequently, weatherseals have been installed on Minuteman motors since June 1980. While weatherseals eliminated the extreme humidity conditions, a concern was raised that motors sealed at low humidity conditions may be prone to excessive surface hardening.

Results of the Surface Hardening Investigation (Reference 5) indicated the service life of the unsealed Minuteman II and III Stage II motors will not be limited by reduction in strain capability at the inner bore prior to the life limit that is based on degradation in strength of the propellant-liner-insulation bond. Service life prediction based on grain cracking indicated a nominal service surface hardening age of 17 to 20 years with a lower 3σ limit of 13 years (based on a value of 9.2% strain at break).

An additional surface hardening program was initiated in 1984 to investigate effects of low-equilibrium moisture on a weathersealed motor. Results indicated that weathersealing Minuteman motors will not increase the rate of bore surface hardening in the humidity range from 10 to 50% RH. For motors sealed at low-humidity levels, the presence of the weatherseal does decrease the rate of hydrolytic degradation of the liner. Propellant surface hardening should now be considered a primary age-limiting factor for weathersealed Stage II motors.

V. SCOPE/STATUS

This report contains information regarding the following program elements for the propellant-liner-insulation system:

- Remnants from previously dissected motors, aged for 234 months
- Propellant removed from motors prior to remanufacture (aft end), aged from 110 to 216 months
- Through-the-case samples (plugs) from a remanufactured motor, aged 18 months
- Propellant from a dissected remanufactured (weathersealed) motor, aged 64 months
- NDT examination of propellant and propellant-liner-insulation bond (original and remanufactured motors)
- Ignition delay investigation (original and remanufactured motors)
- Analog carton samples for propellant lot combinations used in the Minuteman Remanufacture program.

Information is also supplied regarding the following motor components:

- LITVC system
- Internal insulation
- Nozzle

A milestone chart for the various program elements tested during the current report period is provided in Figure 1.

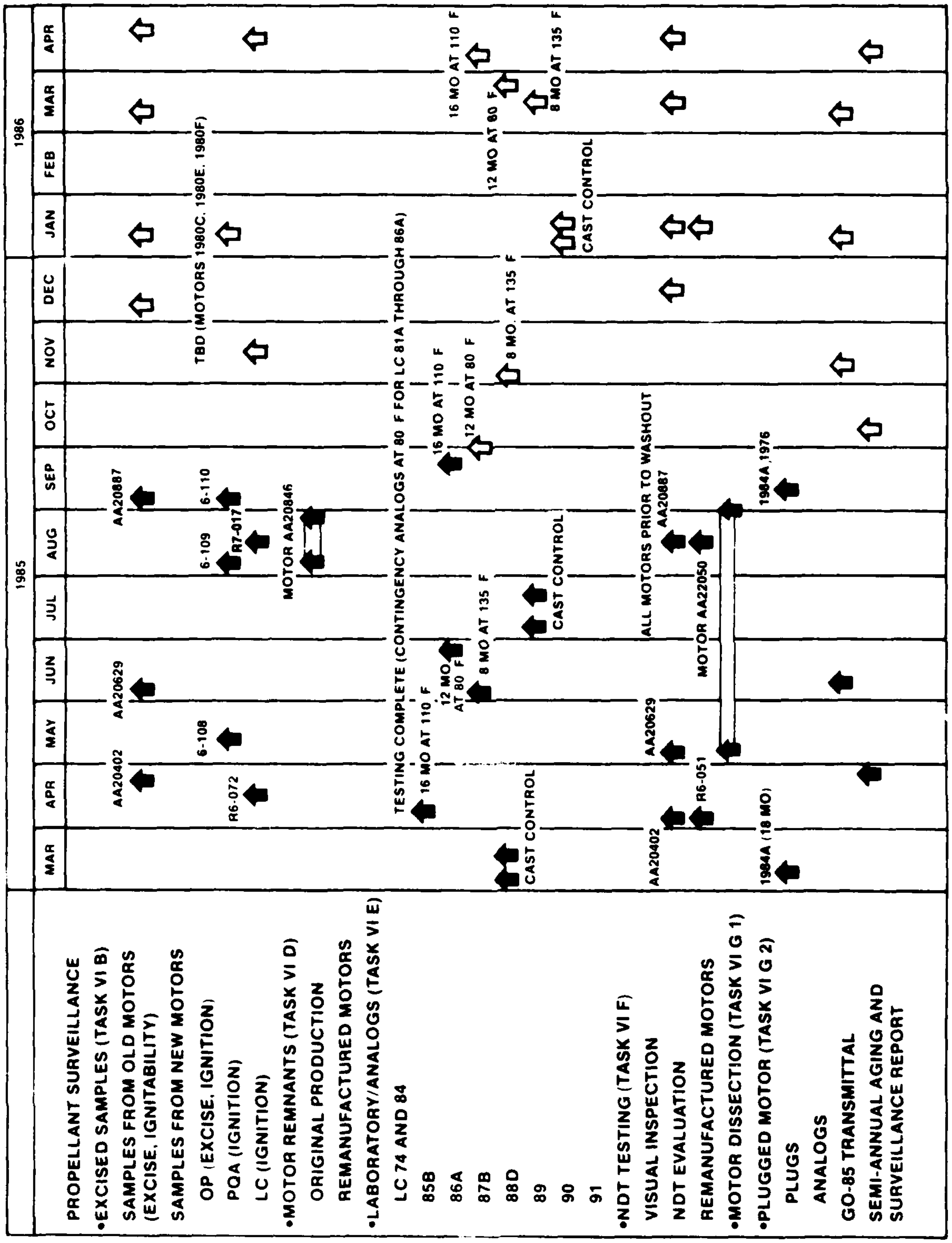


Figure 1. Milestone Chart

VI. TECHNICAL DISCUSSION OF PROPELLANT-LINER-INSULATION SYSTEM

A. MATERIALS FROM MOTORS

1. Introductio

Testing of full-scale motors is currently conducted using material from the following sources:

- Remnants from previously dissected Stage II motors (original production and remanufacture)
- Samples excised from the aft end of
  - OP motors prior to firing
  - Field return motors prior to remanufacture
- Bore samples from the aft bore area of selected motors
- Plugs (through-the-case-samples) from original and remanufactured motors.

Information is also available for materials excised from remanufactured motors, bulk samples from field-returned motors and remnants from Stage III dissected motors. Testing for these samples was discontinued following baseline evaluation.

a. Remnants

The aging program for ANB-3066 propellant, originally based on laboratory samples stored at various elevated temperatures, was supplemented in 1973 by inclusion of remnants from dissected Minuteman II Stage

VI.A. Materials from Motors (Cont)

III motors.* The motor remnants provided information (such as effects of actual storage conditions, geometric considerations, within and between motor variabilities) that was not available from carton samples alone. In addition, properties of materials from dissected motors differed significantly from those of laboratory samples. Initial tangent moduli of aged motor propellant are higher by a factor of two and elongation is correspondingly lower than measured in laboratory samples. The differences between propellant with Phillips and GTR prepolymers were first noted in data from dissected motors.

Limited testing of materials from original manufacture motors (Stage II only) will be continued to provide information regarding long-term aging stability. Testing of remnants from four dissected remanufactured motors is planned. Aged remnants from Motor AA22050 (dissected this report period) will be tested beginning in 1988 per the current test plan.

b. Excised Samples

A total of 24 excised samples of the propellant-liner-insulation system have been removed from the aft ends of Stage II OP motors. The samples were removed at Hill Air Force Base and subsequently fired at AEDC. Data from these samples, tested at Aerojet to evaluate the mechanical and chemical properties of propellant, liner, and insulation prior to firing of the motor, have been combined with similar data from other motors and motor remnants to evaluate aging trends in mechanical and chemical properties. Emphasis has since been placed on performance of remanufactured motors; testing of samples excised from remanufactured OP motors will continue.

To gain more information regarding motor-to-motor variability of aged Minuteman motors, a program was initiated in 1980 to visually examine each motor being returned for remanufacture and remove samples of the

* Same propellant-liner-insulation system as Stage II motors.

VI.A. Materials from Motors (Cont)

propellant and propellant-liner-insulation system from approximately six motors each year. These samples currently include excised samples from the aft end of the motor and a sample from the forward end of the motor to evaluate ignitability. These excised samples, combined with samples from earlier aging programs, contribute to a population of 108 samples excised from full-scale motors.

Data obtained from these samples will be evaluated with respect to motor storage histories to determine effects of variation in operational environments as well as to maintain the correlation between nondestructive tests and excised samples.

c. Bulk (Bore) Samples

In addition to samples excised from the aft end, bulk samples have now been removed from the aft portion of the cylindrical bore section of 25 motors returned for remanufacture. Testing of the bulk propellant has contributed to a database for pertinent structural properties of propellant from aged motors as well as established a correlation between properties of the bulk sample and excised samples from the aft end of the motor. Sufficient data now exist to provide a statistically significant bulk/excised correlation; therefore, routine testing of bulk samples has been discontinued. A 1/3-size "bore" sample has been incorporated into the plug motor test plan to assess effects of aging in the critical bore location. Use of a smaller sample will leave ample material for future sampling.

d. Plugged Motors

The plugged motor concept has been included in the revised test plan. Three full-scale motors of various vintages (manufactured in 1976, 1984, or 1986) will be stored in a carefully monitored environment. Periodic sampling (by removing "plugs" including case, insulation, liner, and

VI.A. Materials from Motors (Cont)

propellant) permits evaluation of aging trends in a realistic stress/strain environment without the complication of motor-to-motor variability. In addition, testing of laboratory samples manufactured and stored with the motor provides information regarding motor/carton bias in properties.

e. Dissection Motors

Four remanufactured (weathersealed) motors, ranging in age from 4 to 9 years, will be dissected over an 11-year period to assess effects of aging on production materials stored under actual environmental and structural loading conditions. Critical areas for evaluation include the forward bore and Y-joint areas, aft Y-joint area, and forward and aft boots. Remnants will be subsequently tested to evaluate effect of aging as well as provide comparisons among motors of various years of manufacture.

2. Scope/Status

The Aging and Surveillance program currently includes remnants from five Stage II motors.* Remnants are tested at regularly scheduled intervals as shown in Figure 2. This report includes results for remnants from Motor AA20013 (aged 234 mo) and Motor AA20846 (aged 174 mo).

Three test matrices planned for use with materials from dissected motors are scheduled on a periodic basis to provide maximum information at a minimum cost. Formats a, b, and c of Test Plan II are used for motor remnants as follows:

* One remanufactured motor: AA22050, cast 7-80
Four original-production motors: OT-11, AA20013, AA20587, AA20846, cast between 1964 and 1971.

Original Motors	Cast Date	CTPB	Test Month	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	2000
QT-11	7-64	GTR	7			b			c											
AA20013	2-65	GTR	3	c			a			b										
AA20587	9-68	PHIL	8	a		b		c			a			b						
AA20846	3-71	PHIL	5		c		a		b			c			a					
MRP Motors																				
AA22050 (1980B)	1980	PHIL			*			a				b				c				
1984B	1984	PHIL						*				a				b				
1980D	1980	PHIL							*				a				b			
1986B	1986	PHIL													*			a		

(Year columns 84–2000 under the heading "Year".)

* Dissection date, initial testing

Note: Letter a, b, or c indicates test matrix **as defined in text.**

Figure 2. Test Schedule for Remnants from Stage II Motors

VI.A. Materials from Motors (Cont)

Format	Material Tested
a	Propellant only, including bore surface
b	Format a plus insulation and propellant-liner-insulation bond
c	Format b plus additional characterization tests for comparison with the LRSLA database

Testing of remnants from dissected remanufactured motors will be incorporated beginning 1988.

This report also includes a summary of test results for samples excised from the following aged motors prior to remanufacture:

Motor	Lot Combo/CTPB	Age at Test, mo	Cast Date
AA20402	20/GTR	216	February 1967
AA20530	27/GTR	203	March 1968
AA20596	29/GTR	180	October 1968
AA20613	30/Phillips	194	December 1968
AA20629	32/Phillips	196	January 1969
AA21321	60/GTR	138	July 1974

During routine examination of Motor AA20629, randomly selected for mechanical and chemical properties evaluation, a propellant crack was identified in the aft nozzle well area. Subsequent to the crack discovery, the scope of testing was enlarged to include propellant samples from the affected areas. Data for the excised samples are included in the database; results of testing conducted on other samples representing Motor AA20629 are summarized in Section VI.C.1.

Motor AA21321, aged 138 mo, was returned for remanufacture ahead of schedule due to extreme liner degradation. Samples were removed from

VI.A. Materials from Motors (Cont)

the aft end to evaluate condition of the material and investigate potential causes for its condition. Motor AA21321 is the second motor identified with a prematurely aged condition.* Subsequent discovery of additional suspect motors (6 total) has prompted an investigation to identify materials or processing variables which may contribute to early age-out. The program is summarized in Section VI.C.2.

This report also includes a summary of data for plugs removed from Motor MSEX-2 at 18 mo [1984A plug motor, (Section VI.C.3)]. Removal of samples from both Motor MSEX-2 (aged 24 mo) and AA21480 (1976 plug motor, initial testing) is complete. Results of testing conducted on plugs and analog samples stored with the motors will be presented in the next report.

3. Mechanical and Chemical Properties

a. Propellant

(1) Bulk Propellant

(a) Uniaxial Tensile Properties

Uniaxial tensile properties were measured at various test conditions for remnants from two motors during the current report period. Location within the motor for the remnants tested is shown in Figure 3.

Results for a remnant from the mid-barrel of Motor AA20013 (aged 234 mo, GTR CTPB) were compared with data for testing conducted following 117, 169, 180, and 204-mo aging. Data indicate little change in properties in

* Motor AA21049, cast 10-72, was returned to ASPC in November 1983 due to excessive boot lifting. Results of testing are presented in SAAS-33.

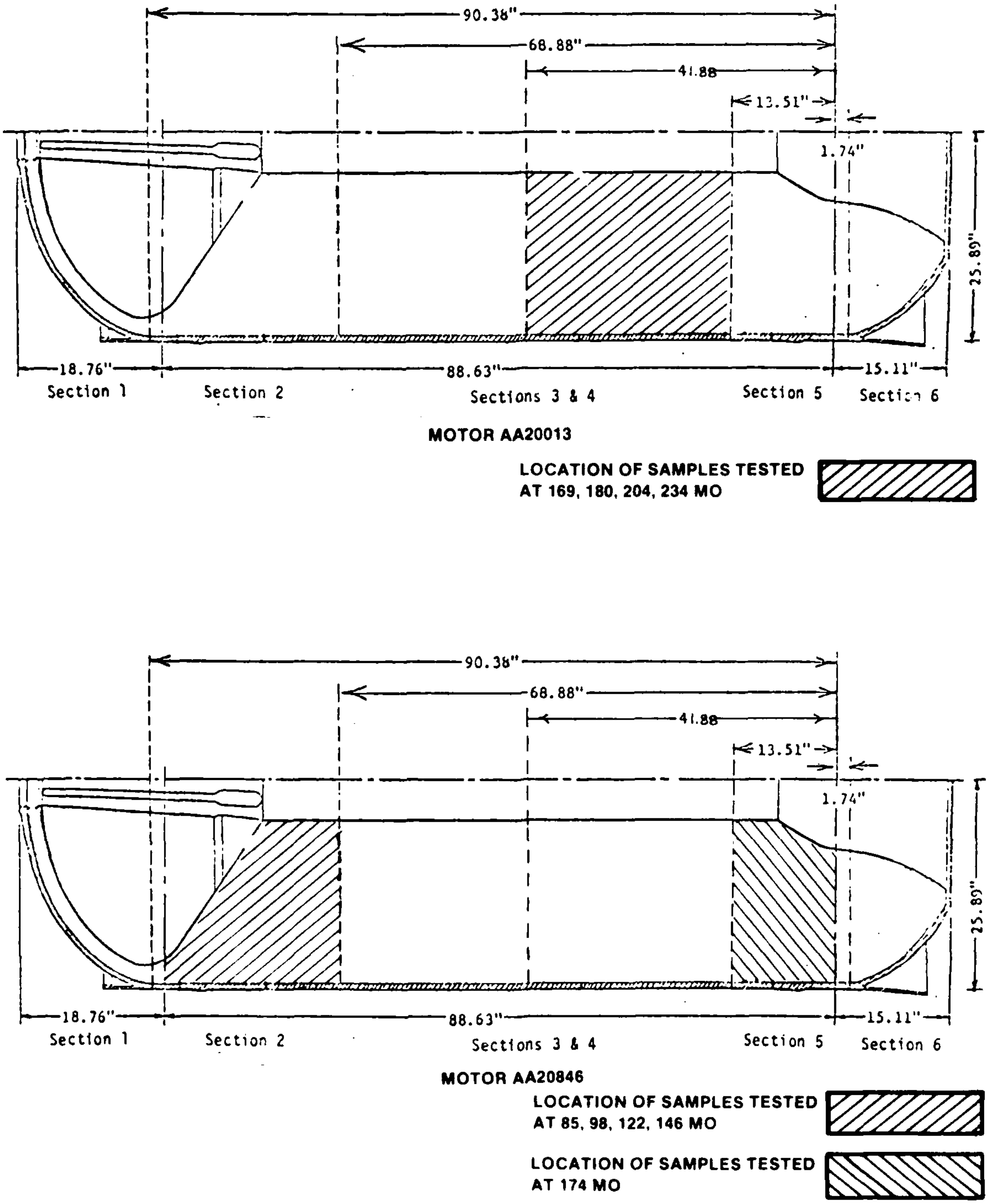


Figure 3. Source of Propellant Remnants from Stage II Motors

VI.A. Materials from Motors (Cont)

comparison with values measured at 180 months. The hardening noted in the last test interval (204 mo) is not supported by recent data. Propellant formulated with GTR CTPB typically does not harden with aging.

Results of uniaxial tensile tests conducted on a remnant from Motor AA20846 (aged 174 mo, Phillips CTPB) indicate softer propellant in the aft nozzle area than in the forward barrel of the motor. (Tests conducted at 98, 122, and 146-mo intervals used material from the forward barrel.) Bulk propellant formulated with Phillips CTPB generally exhibits hardening with age; unexpected softening noted at 174 mo is probably a result of difference in sample location. The aft end is cast from a different propellant batch than the forward barrel: Batch-to-batch variability may be contributing to differences in properties noted between the two sample locations.

Data for samples from Motors AA20013 and AA20846 and corresponding data from previous test intervals are plotted in Figure 4 and tabulated in Appendix A.

(b) Stress Relaxation

Results for stress relaxation tests confirm trends noted for uniaxial tensile properties for both motor remnants.

(2) Gradients from the Bore and Bondline

(a) Uniaxial Tensile

Grain cracking resulting from propellant surface hardening has been identified as a potential mode of failure for the Minuteman propellant-liner-insulation system (Reference 6). As a result, gradients in uniaxial tensile properties as a function of distance from the bore surface were

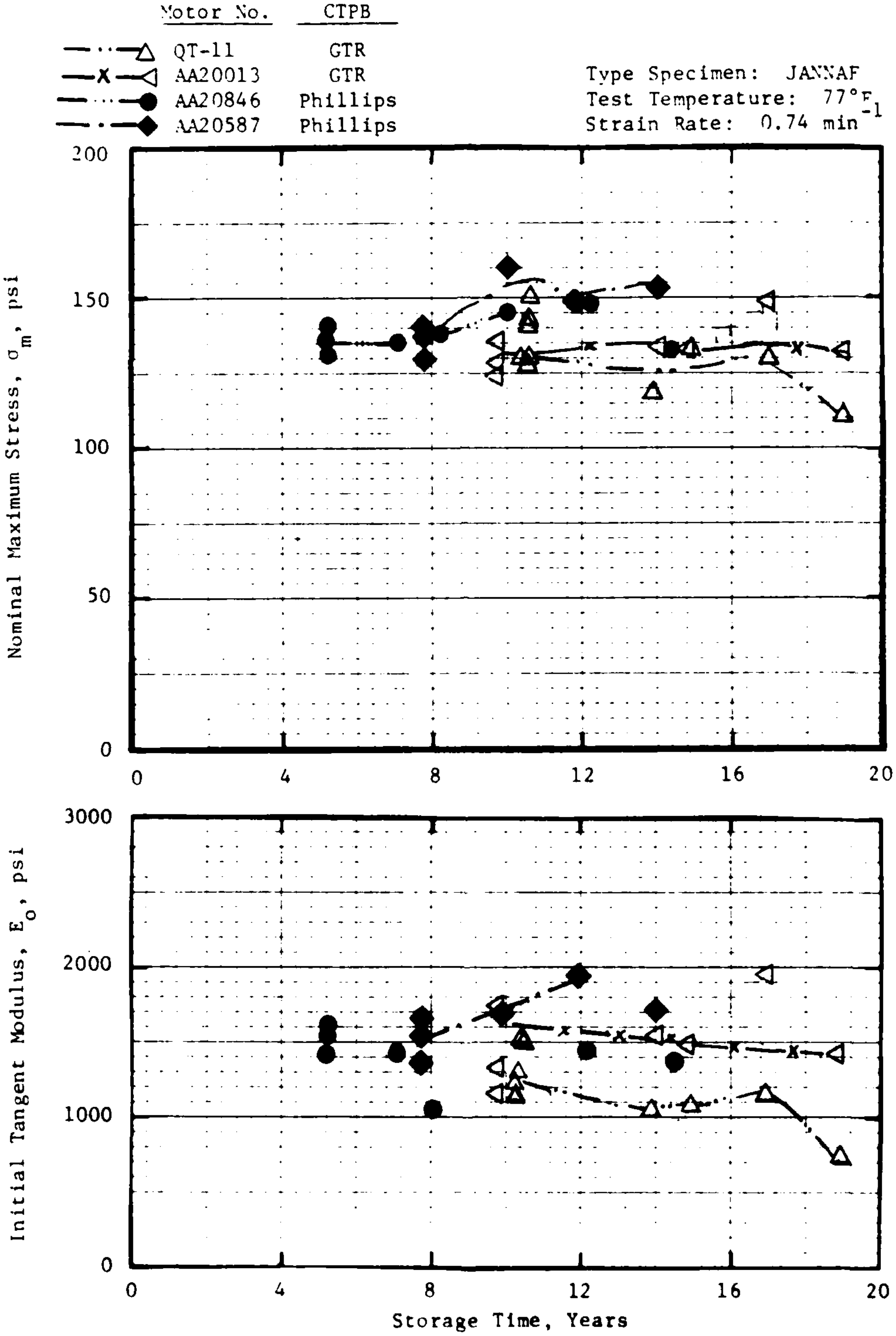


Figure 4. Effect of Storage Time on Uniaxial Tensile Properties of ANB-3066 Propellant from Dissected Stage II Motors (Bulk Propellant), Sheet 1 of 2

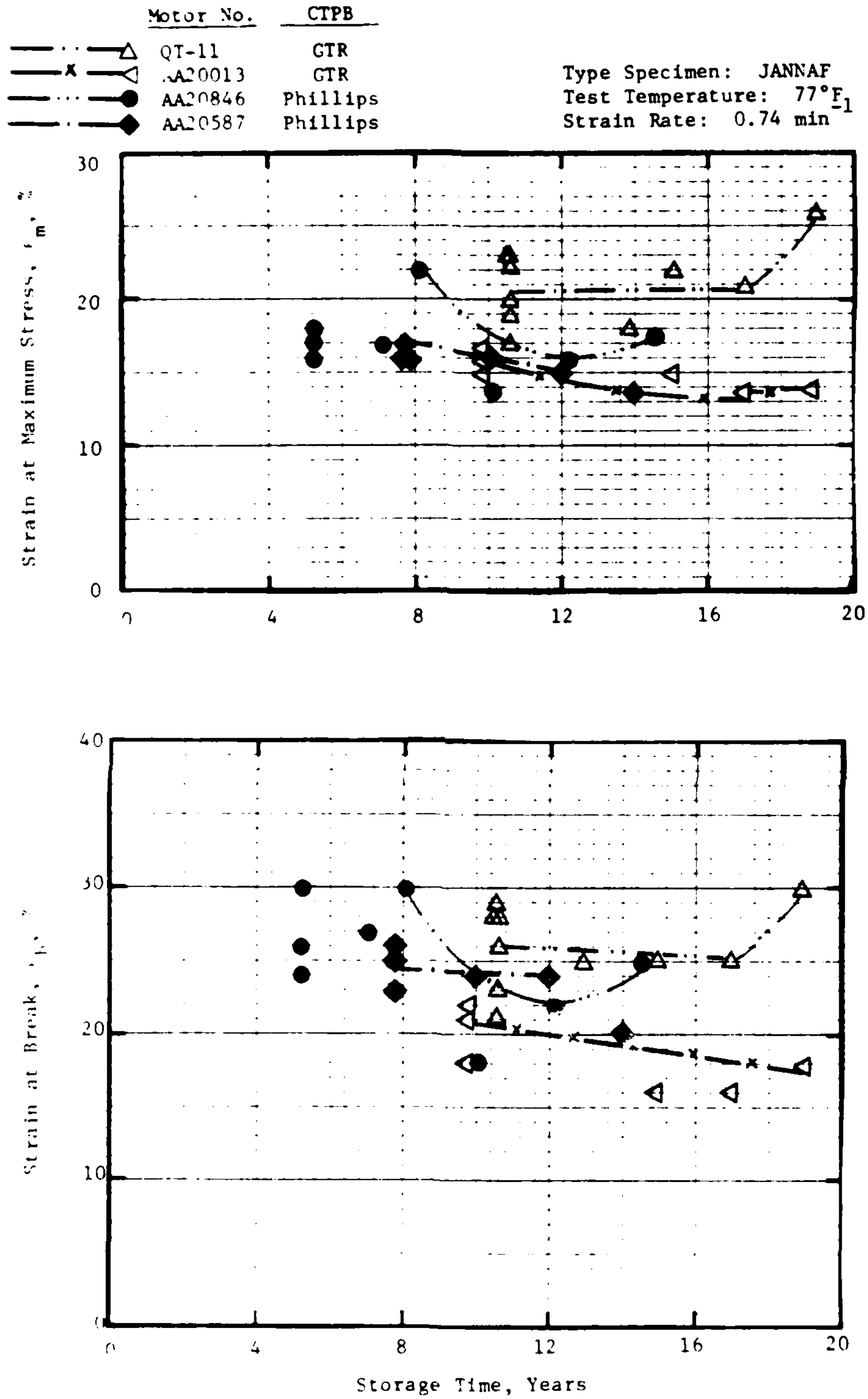


Figure 4. Effect of Storage Time on Uniaxial Tensile Properties of ANB-3066 Propellant from Dissected Stage II Motors (Bulk Propellant), Sheet 2 of 2

VI.A. Materials from Motors (Cont)

evaluated at 77°F, 1.0 min^{-1} for materials from motors tested during the current report period. Results for the remnant from Motor AA20846 (174 mo) compared with those from previous testing continue to indicate the presence of a gradient at the bore surface despite some variability due to sample location. Properties near the bore (0 to 0.5 in. from the surface) have not changed significantly from 146 to 174 mo, but the hardened layer has extended deeper into the propellant with aging. The greatest degree of change occurs at 1.0-in. from the bore.

		Distance from Bore, in.			
Motor	Age, Mo.	0.1	0.5	1.0	2.0
		*	*	*	*
AA20846	85	138/14/17/1276	140/16/20/1064	130/19/21/962	110/24/32/665
	98	153/14/18/1575	154/15/19/1438	153/16/19/1275	124/25/34/770
	122	153/13/16/1932	148/15/17/1473	137/16/19/1336	101/28/40/672
	146	166/13/18/2020	159/15/20/1596	156/16/22/1348	116/28/39/694
	174	149/13/18/1791	153/13/19/1650	156/14/19/1659	108/24/38/714

* $\sigma_m/\varepsilon_m/\varepsilon_b/E_o$

In all cases, propellant at 2 in. from the bore does not undergo hardening noted in the first inch.

Properties near the bore for propellant from Motor AA20013 have not changed with aging. As expected for GTR propellants, data continue to indicate no gradient in properties with respect to distance from bore.

Results of uniaxial tensile tests conducted on samples excised from the aft ends of full-scale motors during the report period have been added to plots and tabulations prepared to assess the effect of aging on

VI.A. Materials from Motors (Cont)

propellant adjacent to the bore (0.1, 0.2, 0.5, and 1.0 in. from bore). (Figure 5). Motors AA20402, AA20530, AA20596, AA20613, AA20629, and AA21321, ranging in age from 138 to 216 mo, have been included. Data show good agreement with previously established trend lines. Propellant formulated with GTR CTPB shows little change with extended storage. However, testing of propellant formulated with Phillips CTPB continues to indicate that significant hardening will be more likely in motors cast with propellant formulated using Phillips CTPB.

Uniaxial tensile properties near the bore for Motors AA20629 (cracked motor) and AA21321 (early age-out) are within the range of values for comparably aged motors. Data are summarized in Appendix A.

(b) Stress Relaxation

Gradients in response properties as a function of distance from the bondline interface were measured at 77°F with 2.0% applied strain for materials removed from all motors tested during the current report period. Data are tabulated in Appendix A and shown graphically in Figure 6. This plot (relaxation modulus as a function of storage time for 108 excised samples) is applicable to tests conducted with 2.0% applied strain; results from previous tests (conducted with 0.5% applied strain) have been adjusted using equations described in SAAS 33. Variability remains large for properties of motors cast with Phillips CTPB.

As previously noted in results of uniaxial tensile tests, Remnant AA20846 shows hardening with additional storage time. Relaxation modulus at one minute has increased 65% at the bondline and approximately 30% at 1.0 in. from the bondline since last tested as shown below:

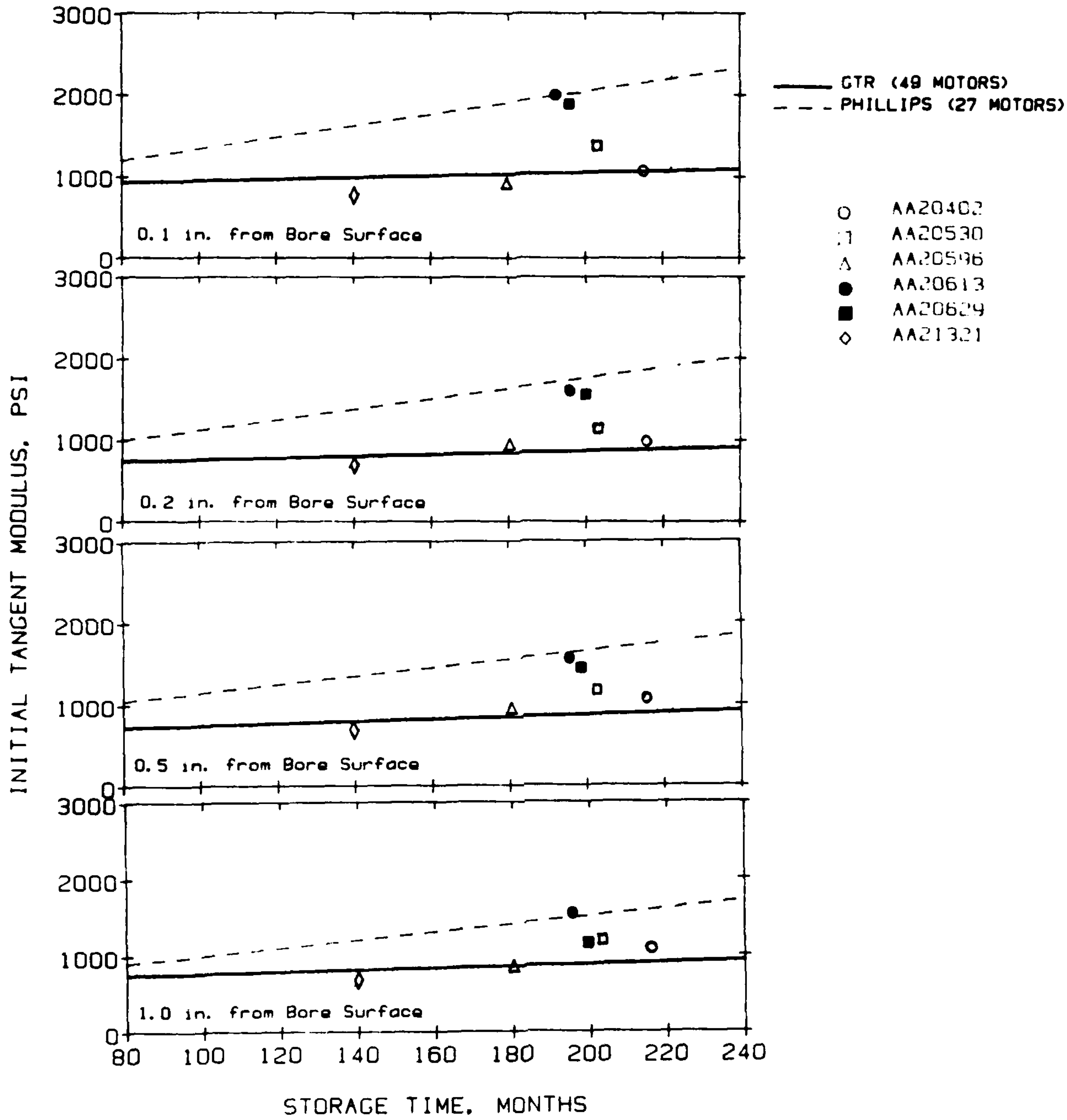


Figure 5. Effect of Storage Time and Distance from Bore Surface on Initial Tangent Modulus for ANB-3066 Propellant Excised from Full-Scale Motors

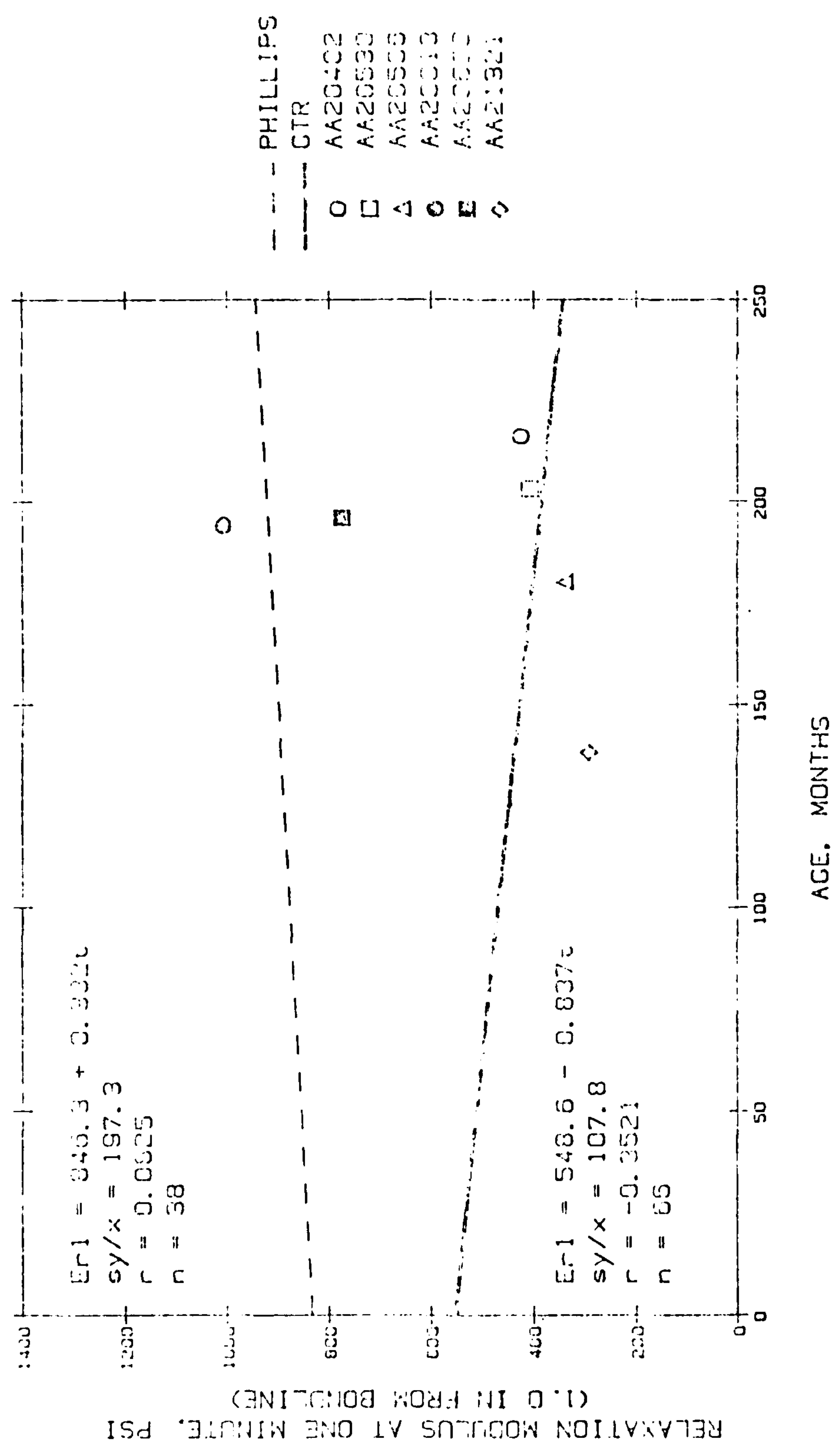


Figure 6. Effect of Aging on Relaxation Modulus of ANB-3066 Propellant Excised From Full-Scale Motors

VI.A. Materials from Motors (Cont)

Age, Months	Relaxation Modulus at One Minute, psi 0.1*	0.2*	0.5*	1.0*
146	818	511	405	510
174	1,346	1,173	576	672

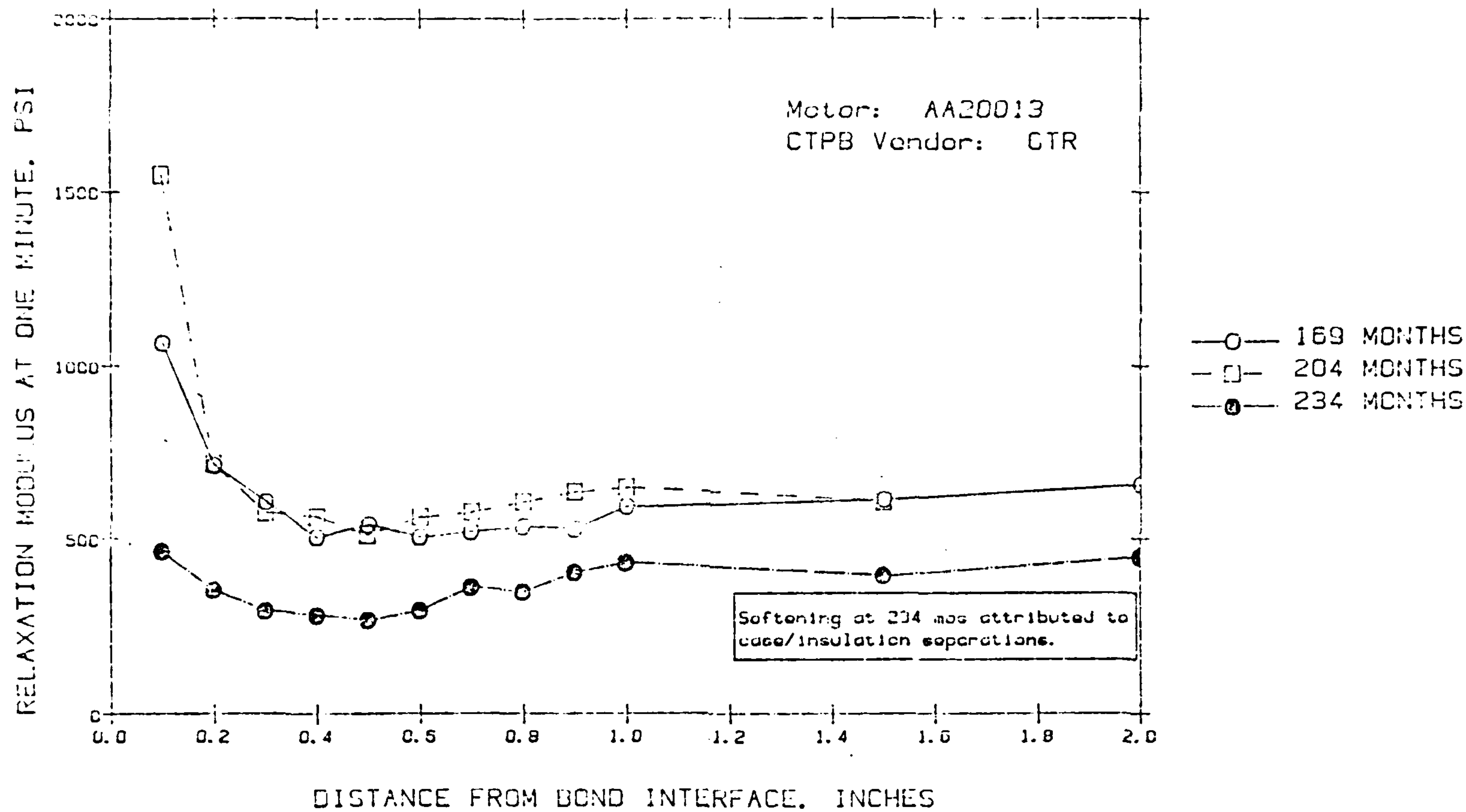
* Distance from bondline, in.

Softening at the bondline, noted for plug samples from Motor MSEX-2 (Section VI.C.3) and laboratory samples [Section VI.B.2.a.(2)], is not apparent in the remnant.

Motor AA20013 experienced case/insulation separation in the mid-barrel. This condition was previously identified during tests conducted on a barrel section at 169 mo and has probably been present since manufacture. Affected areas were probably first exposed to environmental conditions during motor dissection (at 123 mo). As a result, liner and propellant near the bondline have been more susceptible to moisture diffusion across insulation than those areas also protected by the titanium case.* As expected, data indicate extreme propellant softening at the bondline throughout the area measured (depth of 2.0 in. from bondline). While some softening is expected in propellant formulated with GTR CTPB, this degree of softening is considered to be a local effect resulting from case/insulation unbonds in the remnant. Unbonds occurring in a full-scale motor would not affect properties at the bondline: unbonded areas would be protected from diffusion by the titanium case. Relaxation modulus at one minute, E_{r_1}, is plotted in Figure 7 in comparison with previous results.

Results for stress relaxation tests conducted on samples excised from aged motors have been included in Figure 6. In general, test results at 1.0 in. from the bondline continue to indicate differences between

*Insulation in the chamber has a nominal thickness of 0.3 in.



Test Temperature: 77 Deg
Applied Strain: 2.0%

Figure 7. Effect of Aging and Distance From Bondline On Relaxation Modulus of ANB-3066 Propellant

VI.A. Materials from Motors (Cont)

Phillips and GTR propellant, with GTR propellants exhibiting little of the hardening associated with aged Phillips propellants. At the bondline interface, propellant softening is related to degree of liner degradation. In motors where liner has degraded significantly (Motor AA21321, for example), propellant immediately adjacent to the bondline exhibits reduced relaxation modulus in that region.

(c) Chemical Evaluation of Propellant by FTIR (Transmission Spectra of Chloroform Extracts)

A full discussion of FTIR capabilities is presented in SAAS-34.

Gradient from the Bore - Propellant extracts from the bore gradient of remnants from Motors AA20013 and AA20846 (146 and 174-mo aging) were analyzed by FTIR. The absorbance of the 970 WN peak (normalized to initial weight) exhibits changes typical of all CTPB peaks and is indicative of the amount of extractable CTPB.

Slightly more CTPB was extracted near the bore surface of Motor AA20013 compared to Motor AA20846. This was expected as Motor AA20013 is a GTR motor and does not undergo the hardening at the bore surface characteristic of a Phillips motor (see Figure 8).

FTIR analysis of propellant extracts from Motor AA20846 shows little change from 146 to 174-mo aging.

Gradient from the Bondline - Propellant extracts were analyzed by FTIR from the bonded and debonded areas of the remnant from the mid-barrel of Motor AA20013. The absorbance of the 970 WN peak (normalized to initial weight) exhibits changes typical of all CTPB peaks and is indicative of the amount of extractable CTPB.

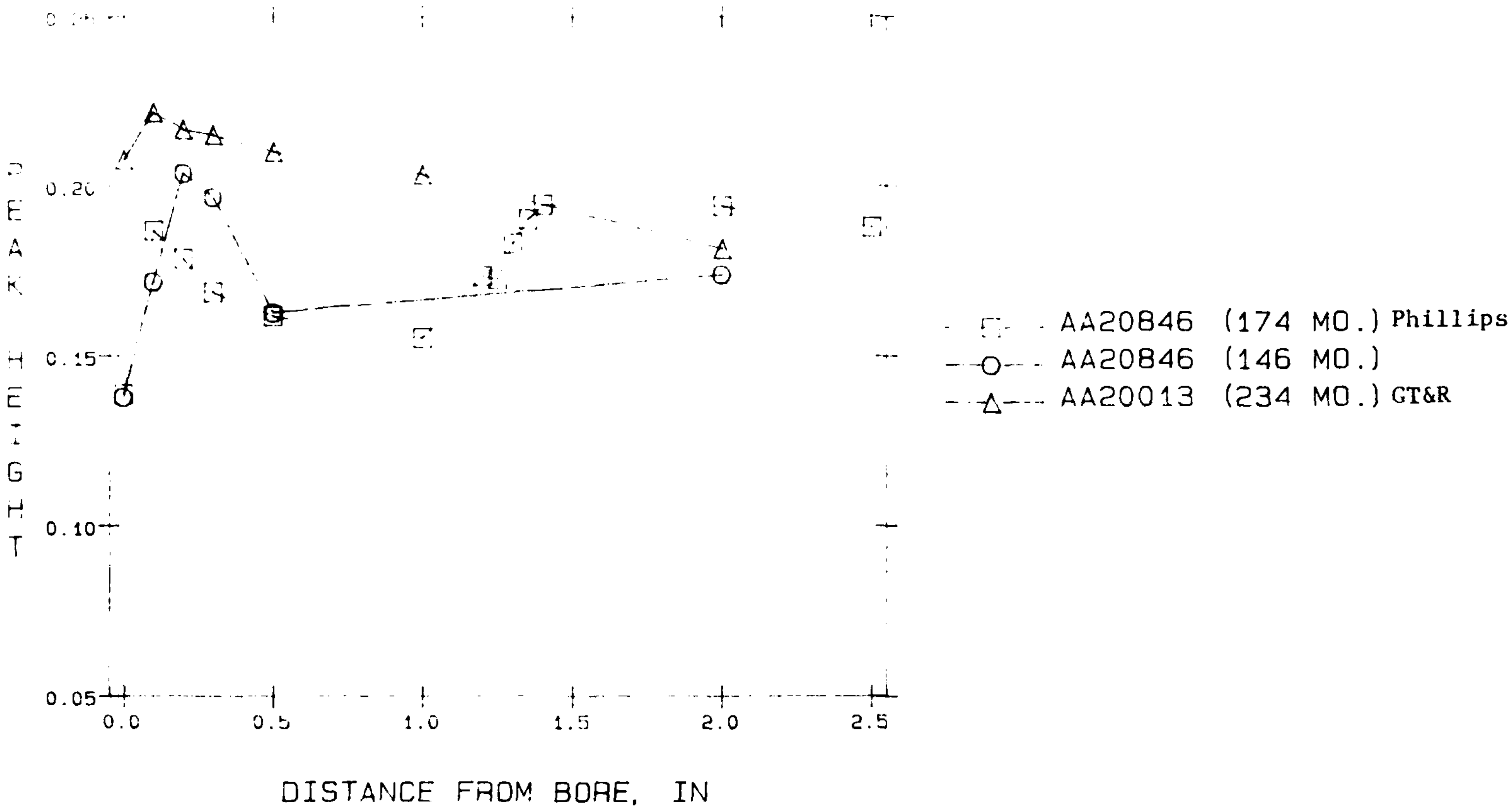


Figure 8. Surface Hardening of Phillips Motor Results in Lesser Amounts of Extractable CTPB; Indicated by Absorbance of 970 WN (Trans C=C) Normalized to Initial Weight

VI.A. Materials from Motors (Cont)

More CTPB is extracted from the bondline interface from the unbonded area compared to the bonded area. This increase is probably due to hydrolytic degradation of the liner aziridines at the bondline interface (migration of liner aziridines into the propellant is discussed in SAAS-34). The unbonded area is susceptible to hydrolytic degradation because the separation of the insulation from the case allows a pathway for the diffusion of moisture after dissection. The extracts from depths greater than 0.1 in. indicate slightly more extractable CTPB from the unbonded area which agrees with the softening noted by mechanical properties (see Figure 9).

b. Propellant-Liner-Insulation Bond

Propellant-liner-insulation specimens were prepared from remnants of Motors AA20013 and AA20846. Results of constant rate shear tests conducted under 600 psig superimposed pressure and constant rate and constant load tensile tests are shown graphically in Figure 10 and tabulated in Appendix A. Data indicate slight reduction in bond shear strength in the aft nozzle area in comparison with testing conducted in the forward bore at 146 months. Bond tensile strength in the chamber is unchanged with aging (for tests at 77°F, 1.0 in./min bond strength is 107 psi at 98 mo, 101 psi at 146 mo, 100 psi at 174 mo). Motor AA20846 is the youngest motor included in the remnant testing program; bond degradation has occurred to some extent in some motors stored for periods exceeding 180 months.

Bond testing for Motor AA20013 was conducted for both case-intact and case-separated areas. As expected, in areas of case/insulation separations bond strength was poor, approximately equivalent to values seen in the degraded aft boot areas. In case-intact areas, bond shear strength was unchanged and bond tensile strength decreased slightly with 30 mo additional storage.

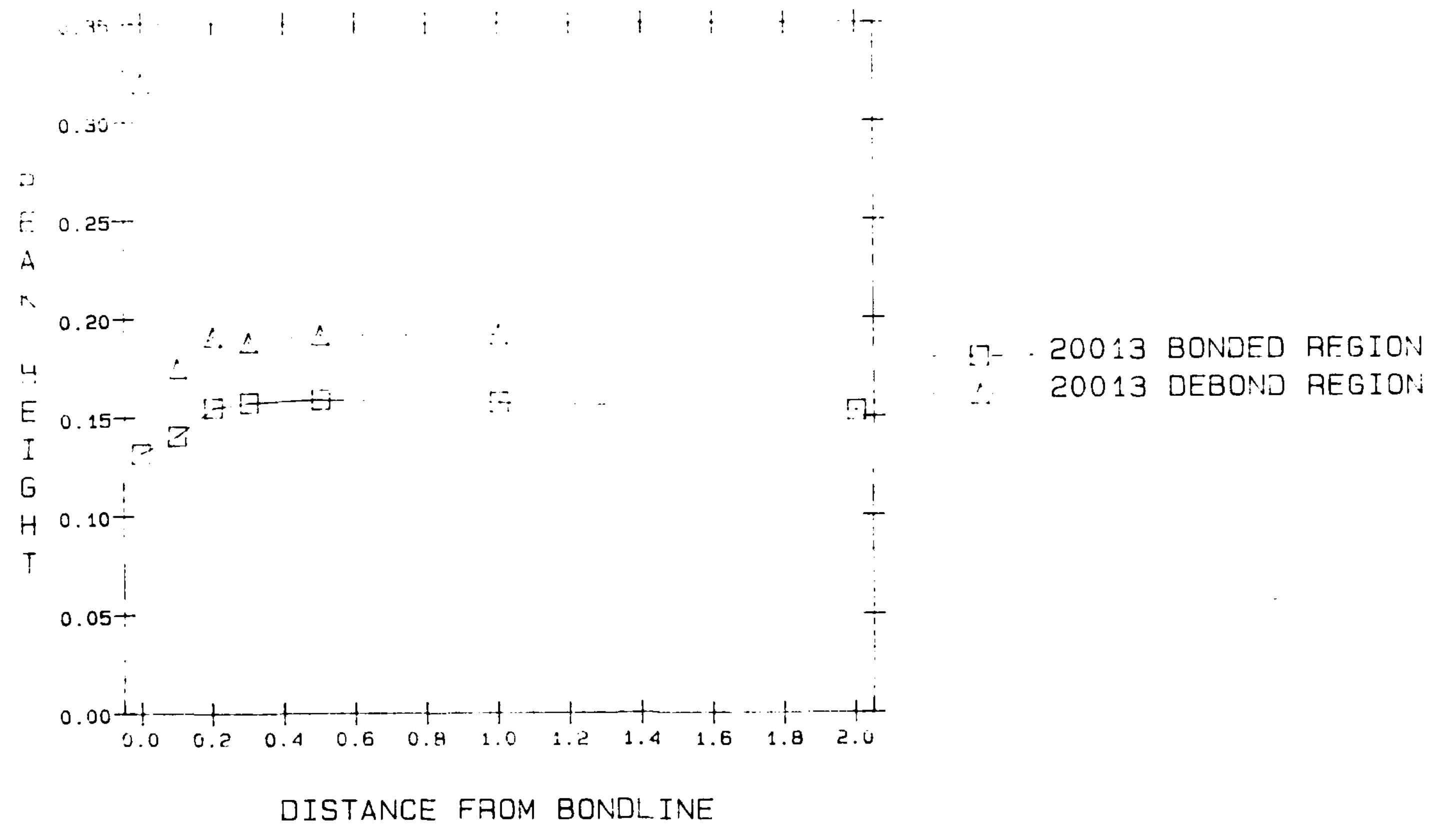


Figure 9. Hydrolytic Degradation at Unbonded Interface Results in Greater Amounts of Extractable CTPB, Indicated by Absorbance of 970 WN (Trans C=C) Normalized to Initial Weight

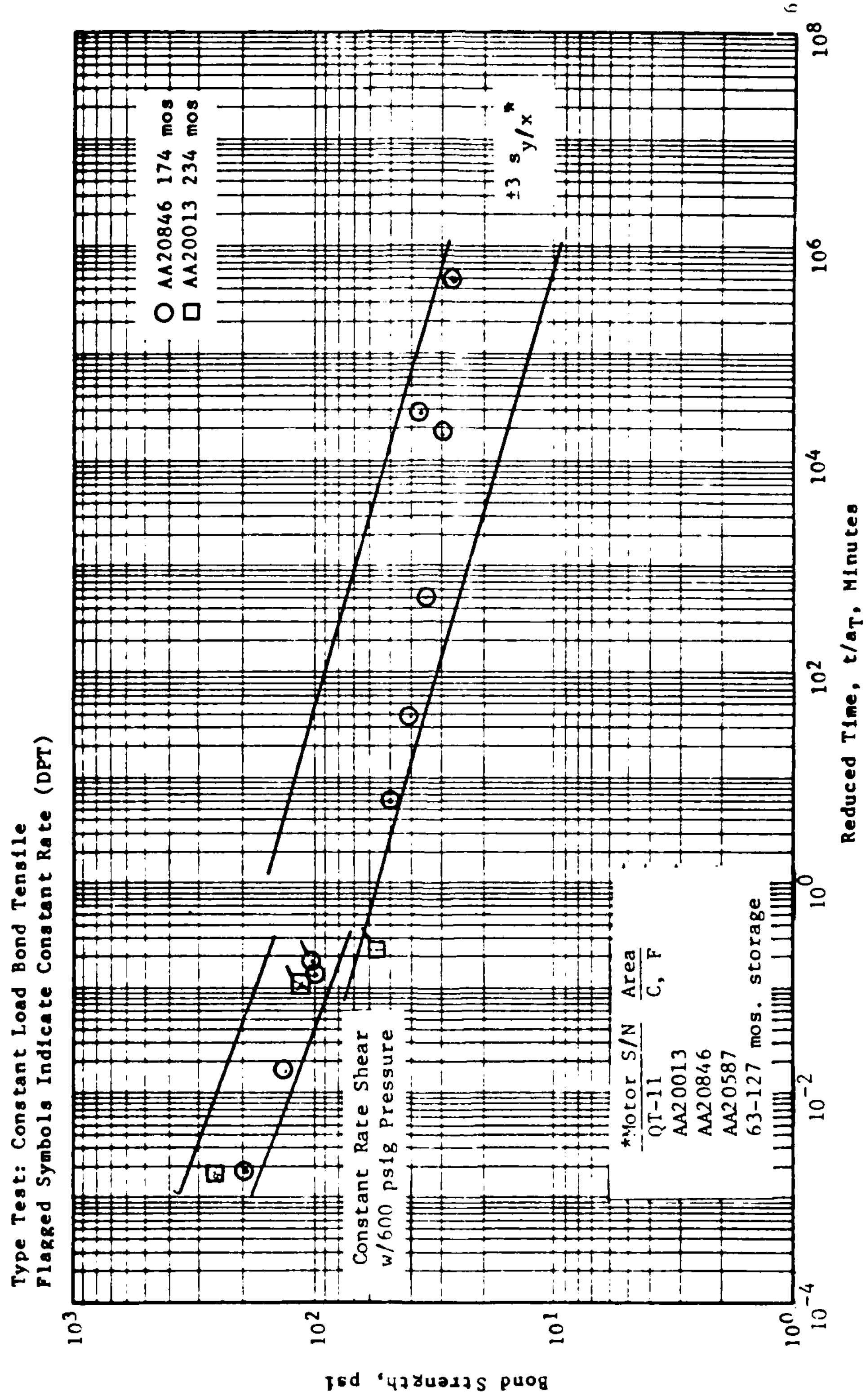


Figure 10. Bond Strength versus Reduced Time for Remnants from Dissected Stage II Motors

VI.A. Materials from Motors (Cont)

Bond tensile strength of samples excised from the aft ends of field-returned motors has been routinely measured to qualitatively evaluate the effects of aging on the bond capability of the system. (A small bond specimen [1.0 x 1.0 x 0.5 in.] tested at a strain rate of 1.0 min^{-1} was selected as a convenient method to monitor bond strength for excised material during the LRSLA program.)

Measurements of bond tensile strength for excised samples tested this report period have been added to a population of 108 samples (Figure 11). With the addition of these samples, measurements of bond tensile strength continue to indicate that significant liner degradation has occurred in the aft boot area after 17 years (~200 months) storage. Bond strengths of Motor AA21321, returned to ASPC at 138 mo due to extreme liner degradation, are below average but within the range of values for comparably aged motors. It is surprising that bond strength is within the range of values, although chemical properties of the liner indicates severely degraded material (Section VI.A.3.C). For severely degraded liner (<20 psi), bond strength measured in a constant rate test at 1.0 min^{-1} no longer relates to liner condition. Chemical testing can provide a better indication of liner condition for severely degraded motors (SAAS-33).

c. SD-85-2 Liner

Chemical test results for liner from the motors tested during GFY 1985 are shown in the following table:

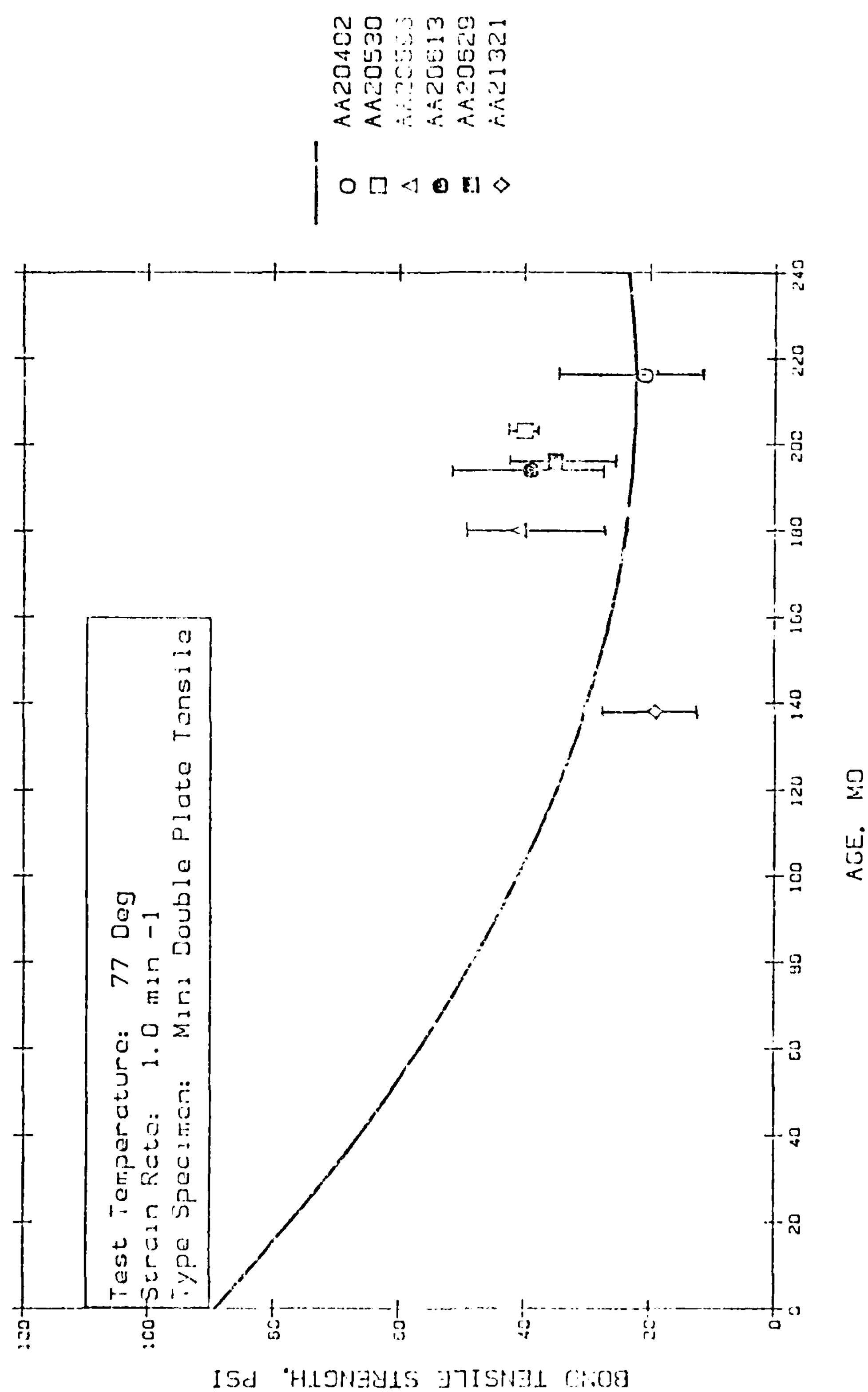


Figure 11. Effect of Aging on Bond Tensile Strength for Samples Excised From Full-Scale Motors

VI.A. Materials from Motors (Cont)

Motor SN	Age, mo	Swelling Ratio	Gel Filler Fraction
AA21321	138	>2.5	0.036
AA20596	192	2.11	0.402
AA20613	194	2.10	0.361
AA20629	196	2.44	0.270
AA20530	203	1.99	0.428
AA20402	216	2.04	0.273
AA20013*	234	1.82	0.580 Bonded
AA20013*	234	>2.5	0.088 Unbonded

*mid barrel of motor remnant AA20013, debonded areas noted at 169 mo testing

It is well established that SD-851-2 liner proceeds through an initial post cure reaction followed by a hydrolytic degradation reaction. Testing of aged motors indicates the presence of degraded liner; however, the extent of degradation depends upon storage environment as well as age.

Gel filler fraction data from current and previously tested motor excised samples is plotted as a function of motor age in Figure 12. The extent of degradation in the liners from five of the excised motors is consistent with accumulated motor data for gel-giller fraction. The liner from Motor AA21321 was totally degraded at 138 months. This motor was rejected from operational use and was identified as prematurely aged. For a complete discussion of early ageout see Section VI.C.3.

Unbonded areas in the remnants from the mid-barrel of Motor AA20013, noted at 169 mo testing, have probably existed since the motor was manufactured and have been exposed to environmental conditions since dissection. As expected, the liner from the debonded areas is severely degraded.

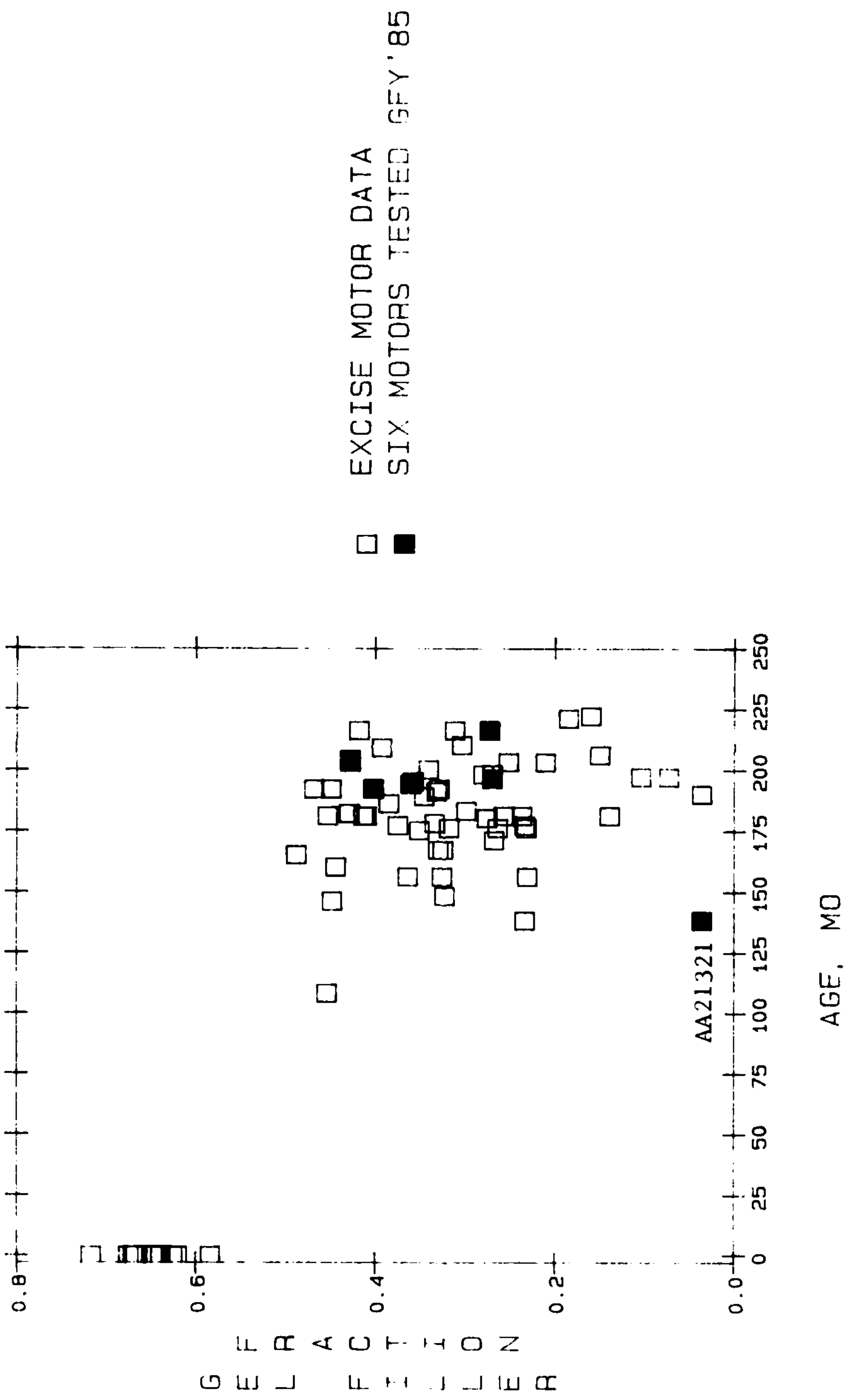


Figure 12. Gel-Filler Fraction of SD-851-2 Liner From Motor Excised Samples

VI.A. Materials from Motors (Cont)

In the bonded area of the remnant, the liner has chemical properties similar to unaged liner, which indicates no exposure to moisture in this area.

Data from testing of all motor excised samples is presented in Appendix A.

d. V-45 Insulation

Shrinkage of the insulation of the motor in the booted area is a major contributing factor to potential motor failure and is a direct result of net plasticizer loss. To monitor the aging behavior of the insulation, response properties of V-45 insulation for motors tested during the report period were evaluated by stress relaxation tests conducted at 77°F with 2.0% applied strain. Values for relaxation modulus at 1 min, E_r, are graphically presented in Figure 13 with results for samples excised from 108 motors tested after storage times ranging to 216 months.

In general, data for motors tested this report period show good agreement with established trend lines. Wide sample variability among 108 motors continues to be evident for properties of V-45 insulation.

The chemical testing conducted on V-45 insulation consists of gel-filler fraction and dioctyl phthalate (DOP) concentration. Data from the motors tested in GFY 1985 is listed in the following table:

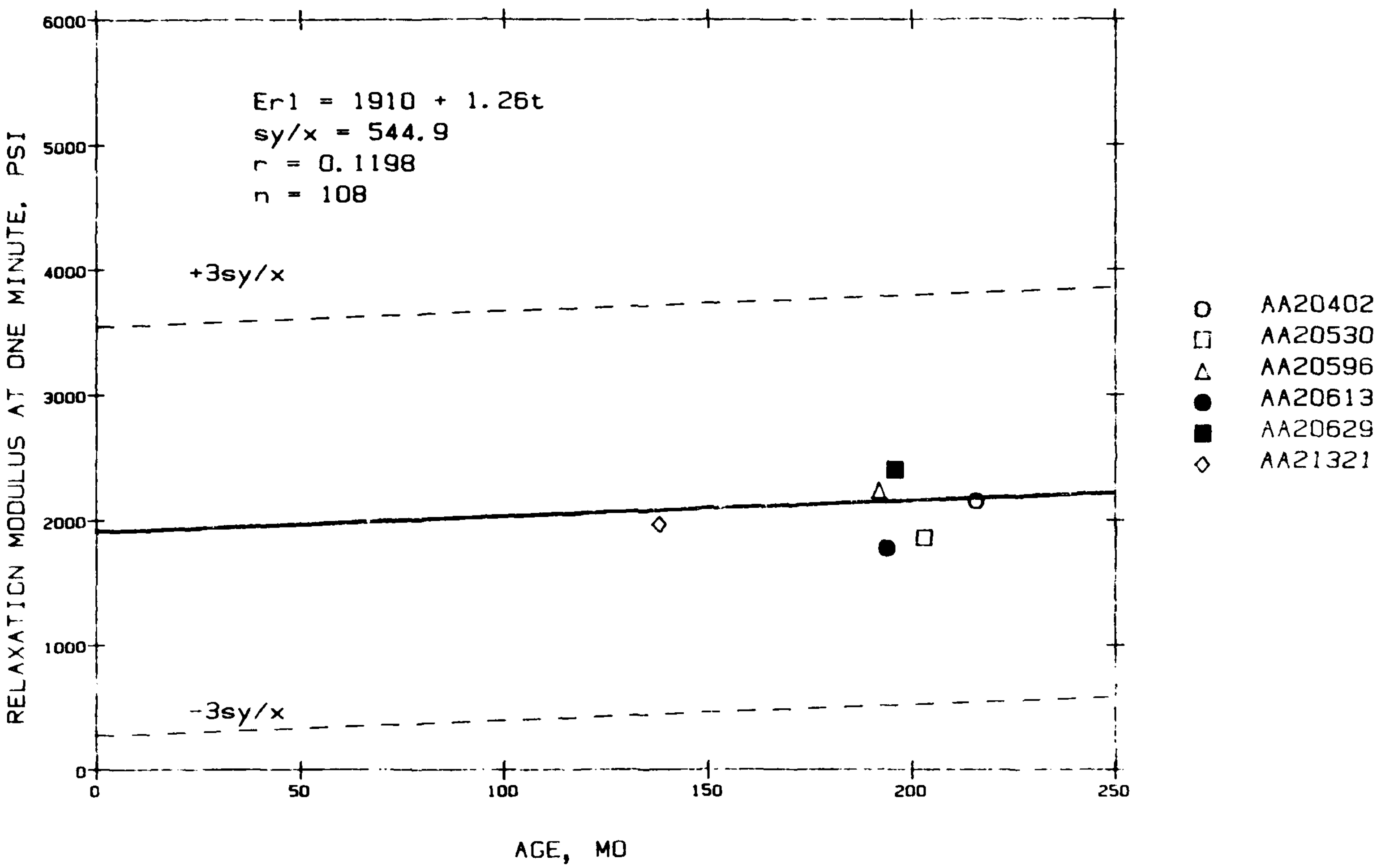


Figure 13. Effect of Aging on Relaxation Modulus of V-45 Insulation From Full-Scale Motors

VI.A. Materials from Motors (Cont)

Motor SN	Age, mo	Gel Filler Fraction	%DOP
AA20596	192	0.893	1.40
AA20613	194	0.899	1.10
AA20530	203	0.898	1.20
AA20402	216	0.897	1.60
AA20629	196	0.885	1.40
AA21321	138	0.891	1.59
AA20013*	234	0.899	0.94 Bonded
AA20013*	234	0.906	0.96 Unbond

*Mid-barrel of motor remnant

These test results are consistent with previously tested motors. A total of 52 motors between the ages of 108 and 220 mo have gel-filler fraction data available. The mean gel-filler fraction is 0.894 (σ = 0.007). The mean concentration of DOP is 1.3% (σ = 0.2). The increase in gel-filler fraction over the average unaged value of 0.841 represents the net effect of DOP loss, Oronite-6 gain (from the propellant), and moisture gain in the insulation.

Data from testing of all samples excised from motors is presented in Appendix A.

4. NDT Examination of Motors

a. Visual Inspection

The objective of visually inspecting Minuteman Stage II motors from the Motor Remanufacture program is to determine long-term aging

VI.A. Materials from Motors (Cont)

effects on the propellant, liner, and insulation. Bond system quality is based on boot gap and boot lifting from the propellant on the forward and aft ends of the grain. In the forward end, measurement of nipple lifting and movement with respect to the propellant is made at the 0-degree location. On the aft end, boot lifting and movement of the boot with respect to the propellant are measured at the 180-degree location. The 0- and 180-degree locations are used because they typically are the areas with the greatest lifting and boot movement.

An estimate of overall propellant quality is made on the motor by measuring slump (insulation-to-boot gap) and by visual observation of cracks, voids, discoloration, and AP on the surface of the propellant. In addition, Shore A measurements are made at the forward, bore, and aft sections of the grain to determine propellant surface hardness. From these findings, general quality of the motor grain is classified as fair, poor, or very poor. A "good" grain condition would be as-manufactured (zero age). A chart showing how the ratings are derived is presented in Appendix A, Figure A-30.

Since the last report period, the following 31 motors were visually inspected.

Phillips	GTR		
AA20629	AA20402	AA20543	AA20586
AA20631	AA20478	AA20548	AA20591
AA20557	AA20490	AA20561	AA20662
AA20808	AA20514	AA20565	AA20706
AA21480	AA20515	AA20572	AA20710
	AA20526	AA20574	AA20717
	AA20533	AA20575	AA20725
	AA20538	AA20576	AA20740
	AA20542	AA20584	

VI.A. Materials from Motors (Cont)

A visual inspection summary for the motors listed is located in Appendix A, Figure A-16. A visual inspection for all motors inspected to date is located in Appendix A, Figure A-17.

For all motors tested to date, GTR (CTPB) motor condition averaged slightly better than Phillips (CTPB) motor condition. Of GTR motors inspected, 51% were rated at fair, while 44% of all Phillips motors inspected were rated as fair. The average age of GTR and Phillips motors is 192 and 194 mo, respectively. Since age difference is small, age was eliminated as a factor in motor condition difference between GTR and Phillips motors. Motor rating by CTPB populations is shown below:

Percent of Each Motor Rating in Each Motor Population

	GTR	Phillips	Pooled (Phillips and GTR)
Fair	51%	44%	48%
Poor	31%	43%	36%
Very Poor	18%	13%	16%
	100%	100%	100%

When motor condition is plotted against age, a correlation is seen where older motors tend to be in poorer condition. This correlation is not surprising and exists when all motors are pooled as one population or when motors are separated by CTPB manufacturer. Field returned motors are usually between 15 to 18 years old: an age-to-motor condition comparison for these motors show that small age differences can have a significant effect on condition for this age range (Figure 14).

Inspection of Motor 4A20629 revealed an 11-in.-long, 1-in.-deep crack in the aft well of the propellant grain. The crack was located at approximately 270 degrees, and was determined to be a result of

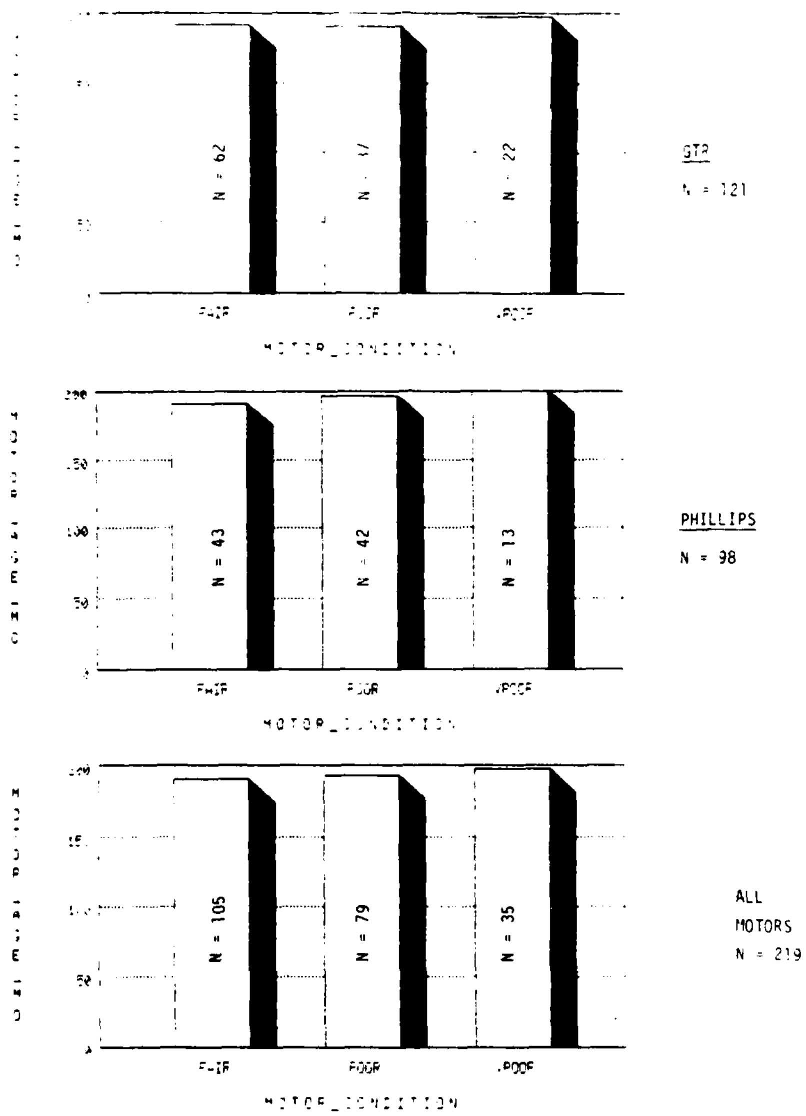


Figure 14. Plots Showing Motor Age vs Motor Condition

VI.A. Materials from Motors (Cont)

motor manufacturing rather than aging. See Section IV.C.1 of this report for a complete description of investigation results.

Inspection of Motor AA20576 revealed a crazed propellant surface on a fin adjacent to the nipple at approximately 180 degrees. The crazing was located inside a 2-in.-long, 1/2-in.-wide, by 1/2-in.-deep void. The cause of the crazed surface is unknown, but this condition was local and would not have affected motor performance. Motor age was 204 mo at the time of inspection and the motor was rated to be in very poor condition.

The visual inspection data base at ASPC has been augmented by visual observations at OO-ALC, which is usually restricted to observations through the igniter boss because of motor disassembly limitations. These data are an important addition to the present database because it represents motors from a younger population increasing the range of motor ages inspected. The boot gap data are used in section IV.C.2 of this report as part of the special section on Early Age-out investigation. The OO-ALC data is located in Appendix A, Figure A-17.

b. On-Surface Evaluation

Six Washout, three Lot Combo, three PQA, and one Plug motor were tested for on-surface Shore A. The test results are summarized in Appendix A of this report.

The mean value of E_o (initial tangent modulus) is derived from the E_o values taken at seven axial locations throughout the motor. This parameter was selected because it has the best correlation (0.96 correlation coefficient) to the uniaxial tensile properties at 0.1 in. from the propellant surface. Test locations and data values for each motor can be seen in Figure A-19 of Appendix A.

VI.A. Materials from Motors (Cont)

Phillips Motors AA20613 and 1976A (plug motor) compared favorably to the mean E_o for Phillips motors. Motor AA20629, which had a crack in the propellant grain, was 17.7% lower than the mean, shown in the following table.

Motor	CTPB Vendor	E_o, psi	Mean E_o, Washout	Var % (+, -)	Age, mo
AA21480 (Plug Motor 1976A)	Phillips	1,634.2	1,679.7	-2.7	110
AA20629	Phillips	1,381.1	1,679.7	-17.7	197
AA20613	Phillips	1,675.2	1,679.7	-0.20	208

Plug Motor (1976A): because this motor is approximately 10 years old, it was ranked with the data for Phillips washout motors.

GTR motors AA20596, AA20530, and AA20402 show properties comparable to other motors of similar age. Their E_o does not vary significantly from the mean.

Motor AA21321, the early age-out motor, has a mean E_o that is 35% lower than the mean for GTR motors. Although this motor is nearly 12 years old, it has surface characteristics comparable to one month old remanufactured motors. Visual observations of this motor revealed aft propellant slump to the extent that aft boot-to-propellant separation could not be measured in the 0 degree quadrant. GTR data are shown below.

VI.A. Materials from Motors (Cont)

Motor	CTPB Vendor	E_o, psi	Mean, E_o Washout	Var % (+,-)	Age, mo
AA21321	GTR	708.4	1,097.6	(-)35.0	132
AA20596	GTR	1,148.8	1,097.6	(+)04.5	193
AA20530	GTR	1,069.8	1,097.6	(-)02.5	203
AA20402	GTR	1,260.8	1,097.6	(+)12.9	217

The mean E_o for remanufactured motors shows a wide range of variation from the mean of all remanufactured motors; +13.3% to -31.6%. Since these motors are tested within a month of the cast date, these variations are probably the result of surface changes related to the curing process.

Motor	CTPB Vendor	E_o, psi	Mean, Eo Regrain	Var % (+,-)	Age, mo
R6-049	Phillips	780.2	966.4	(-)19.3	1.00
R6-072	Phillips	875.7	966.4	(-)9.4	1.00
R7-017	Phillips	749.5	966.4	(-)22.4	1.00
PQA6-107	Phillips	885.8	966.4	(-)08.3	1.00
PQA6-109	Phillips	660.7	966.4	(-)31.6	1.00
PQA6-108	Phillips	1,115.2	966.4	(+)13.9	2.75

c. Ignitability (IDM and SEM Testing)

Ignitability testing is performed on selected old and regrain Minuteman Stage II motors. Propellant is excised from the forward fin slots and tested using the Ignition Delay Motor (IDM) and SEM. SEM analysis reveals surface features which may affect ignitability. The IDM is a small ballistic model designed to dynamically simulate the ignition transients and flame propagation of the Minuteman Stage II motor.

VI.A. Materials from Motors (Cont)

During this reporting period four washout motors (AA20402, AA20629, AA21480, and AA21321), one lot combination motor (R6-072), and two production quality assurance (PQA) motors (R6-069 and R7-014) were tested. Samples were also excised from R7-017. Testing is in process. Ignitability testing and SEM results for these motors are reported in the testing summary in Appendix A of this report.

The quality of samples excised from motors has been unpredictable. Excise tooling produces good samples from some motors and poor samples from others. The better samples are consistently obtained at 0 deg and poorer samples are obtained at 90 and 270 deg. Samples taken from the fins on the sides of the bore have a tendency to be lightweight and wedge shaped. A poor fit between the excise tooling and the fin geometry is a suspected cause of misshapen samples. The present excise tooling design has enough flexibility to accommodate discrepancy between tooling and propellant through small, progressive adjustments rather than drastic tooling redesign.

Recent regrain motors present a more severe problem. The condition of the surface at the top of the fin slots has been consistently rough on all regrain motors (Lot Combo and PQA) tested recently. This condition appears to be the result of the finish of the fin core release. The impact of this rough surface on ignitability testing is to introduce a variable into the testing scenario that has not been characterized or evaluated. The increased surface area of recent samples should cause faster ignition but the effects of humidity conditioning prior to firing and the differences between mechanically induced distortion versus humidity or age-driven deformation are unknown. Long term aging effects are unknown, although the use of the weather-seal in eliminating moisture recirculation is expected to prevent aging changes. This has been demonstrated in the igniter where propellant with the polymer layer removed showed no change with aging.

VI.A. Materials from Motors (Cont)

Since IDM test results are used to predict full-scale Minuteman Stage II ignition delays, a prefire prediction for PQA 6-108 was issued. The test results and predictions appear to be anomalous (see discussion in Appendix A). PQA 6-108 had not been fired during this reporting period. The prefire report for PQA 6-109 will be prepared upon completion of testing.

B. LABORATORY SAMPLES

1. Introduction

Analog carton samples prepared as shown in Figure 15 are used to monitor the aging behavior of ANB-3066 propellant used in the Minuteman Remanufacture program. The sample, designed to simulate the surface-to-free volume ratio in the bore of the Minuteman Stage II motor, is sealed to represent a motor with a weatherseal in place. Samples representing each propellant lot combination are tested after designated periods of storage at 80, 110 and 135°F to provide assurance that no unexpected variation in stability occurs with changes in materials or processing.

To ensure that propellant representative of full-scale motors is being monitored, analog samples are now prepared from propellant batches used in the sixth motor cast for each lot combination (as opposed to use of DW qualification batches). Samples from Lot Combinations 85A, 85B, 86A, 87B, 88D and 89A have been cast from motor batches.

Although previous studies have indicated that significant differences exist between properties of propellant cast into motors and properties for laboratory samples, it is expected that aging trends will be similar.

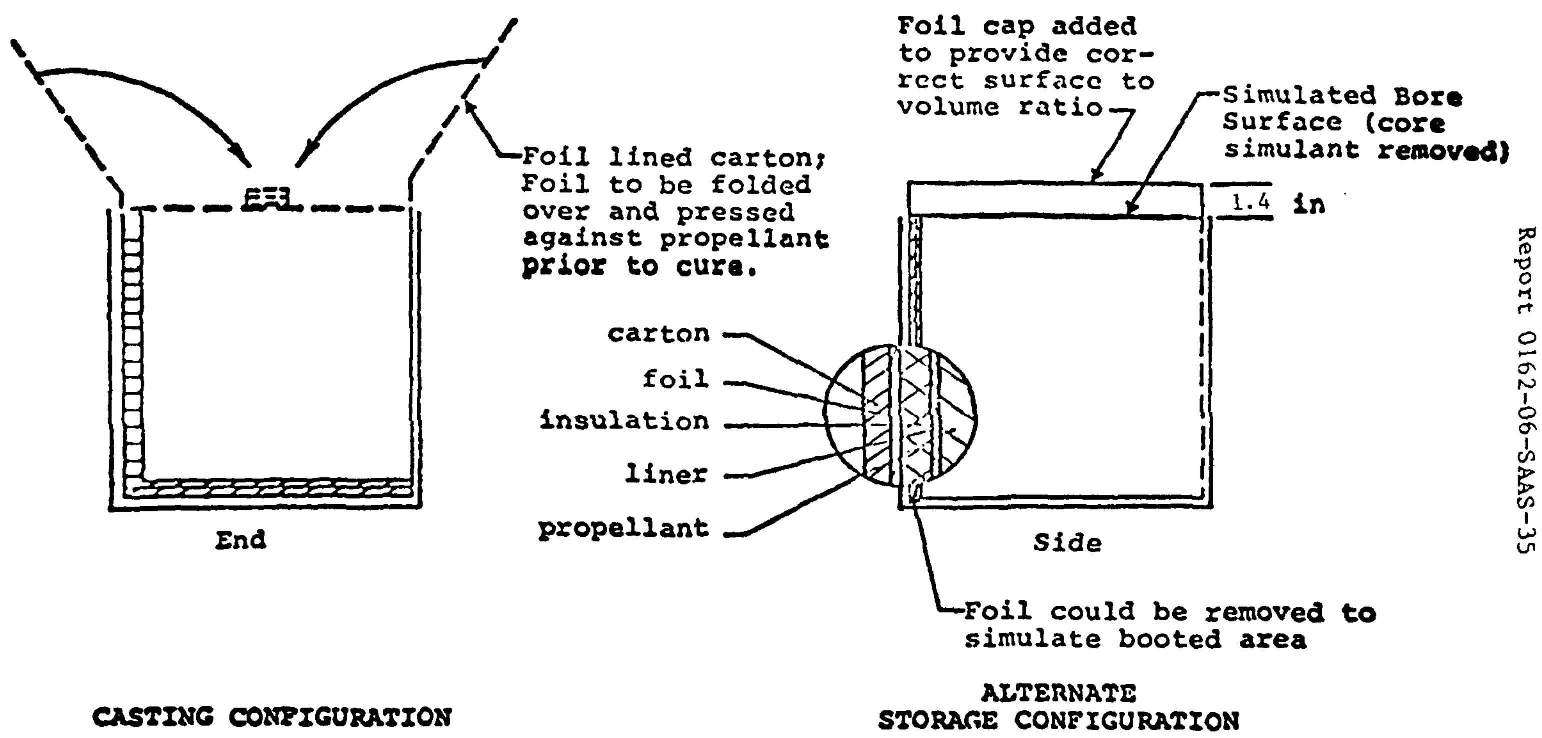


Figure 15. Configuration of Analog Aging Samples

VI.B. Laboratory Samples (Cont)

Testing is complete for Lot Combinations 74 through 84. Samples obtained from Lot Combinations 85A through 89A have been tested after storage at the following conditions:

Lot	80°F		110°F	135°F
Combo	Control	12 mo	16 mo	8 mo
85A	X			X
85B	X	X	X	X
86A	X	X		X
87B	X			X
88D	X			
89A	X			

2. Mechanical and Chemical Properties

a. Propellant

(1) Bulk Propellant

(a) Uniaxial Tensile Properties

Uniaxial tensile properties of control and aged samples were measured at 0, 40, 77, and 110°F at a strain rate of 0.74 min^{-1}. Tests conducted at 150°F, 0.0074 min^{-1} and 77°F, 100 min^{-1} at 1,650 psig were added in the revised test plan to measure performance of the propellant at test conditions related to operational storage and firing loads. Test results from samples tested this report period (Lot Combinations 85A through 89A) are tabulated in Appendix B*.

*Results of tests conducted on Lot Combination 74 through 84 are available in SAAS-33.

VI.B. Laboratory Samples (Cont)

Values of uniaxial tensile properties measured at 77°F, 0.74 min^{-1} for unaged samples from 16 lot combinations have been plotted in control chart format in Figure 16. Data indicate wide variability in modulus and strength for unaged propellant. Moduli of samples from 86A, 87B, and 88D are among the highest to date. On the basis of past experience, it is expected that these lot combinations will age at rates faster than average: Lot Combinations 77 and 78, also high initially, showed the greatest increase in properties with aging.

Data measured at 77°F, 0.74 min^{-1} have been combined to assess aging behavior of the total population at several aging conditions. Although additional data are available for unaged samples, the sample size for the unaged population was limited to results from Lot Combinations 76 through 85B to provide a direct comparison in properties between the aged and unaged populations (i.e., for the same batches). Cumulative frequency distributions of uniaxial tensile properties for control and aged populations are plotted in Figures 17 through 19. This approach is useful in estimating the mean, variability and normality of the population and the approximate magnitude of change in properties with aging.

The data have been plotted on logarithmic paper as a means of normalizing variability in properties on a basis of percentage increase. The roughly parallel slopes of the data for the unaged and samples aged at elevated temperatures suggest little change in percent variability with aging.

The irregular slope of the cumulative frequency curve for the samples aged at 80°F for 12 mo indicates greater variability in properties at that condition. This increased variability suggests that at 80°F, expected propellant hardening related to postcure is not complete following 12-mo storage. Following storage at high temperatures, variability in properties goes down as samples reach the same level of cure (indicated by shallower slope for

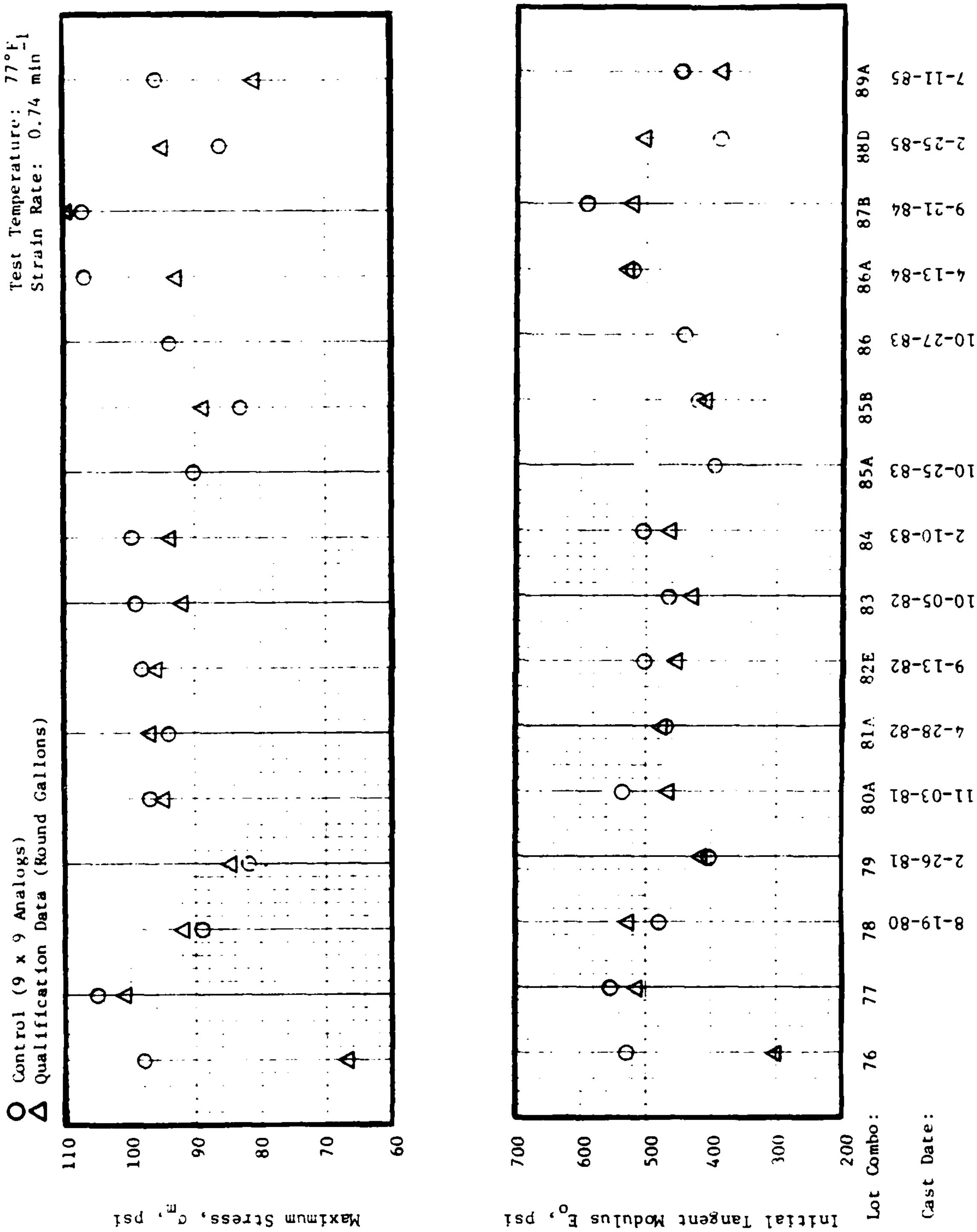


Figure 16. Control Chart of Uniaxial Tensile Properties for Lot Combinations 76 Through 89A, Unaged, Sheet 1 of 2

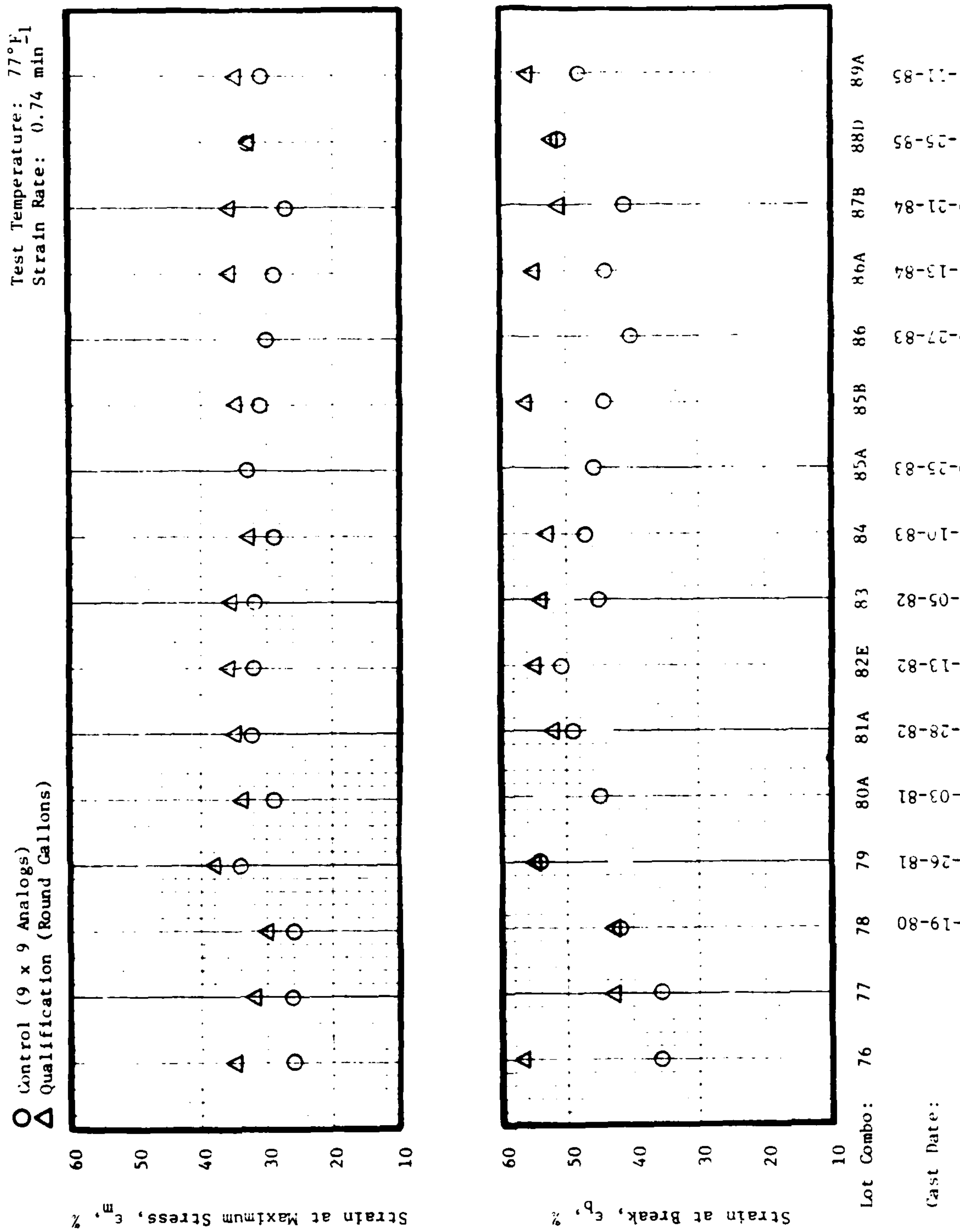


Figure 16. Control Chart of Uniaxial Tensile Properties for Lot Combinations 76 Through 89A, Unaged, Sheet 2 of 2

VI.B. Laboratory Samples (Cont)

110 and 135°F aging in Figures 17 through 19). High variability at 80°F indicates factors in addition to elapsed time can influence the rate of cure for ANB-3066 propellant. Work will continue to evaluate effects of formulation variables and process changes on aging behavior for propellant lot combinations.

In general, the lot combinations tend to age at approximately the same rate; that is, a lot combination whose modulus is initially highest of the population will be found in the high range of aged samples. (Exceptions for Lot Combinations 77 and 78 have been previously noted.) Propellant for Lot Combination 85B, included this report period, behaves as expected in comparison with other batches.

The average (median) increase in properties for the population (10 lot combinations, Figures 17 through 19) following storage at several aging conditions is shown below.

	Normalized Properties (Aged/Unaged)			
Aging Condition	σ_m	ε_m	ε_b	E_o
Unaged (Median)	93	35	52	455
Unaged	1.00	1.00	1.00	1.00
12 mo at 80°F	1.22	0.74	0.68	1.40
16 mo at 110°F	1.56	0.62	0.50	2.20
8 mo at 135°F	1.64	0.56	0.43	2.59

The values for normalized properties have been plotted in Figure 20 as a function of equivalent storage time at 80°F. As expected, most severe changes in properties occur at elevated storage temperatures. On the basis of kinetic evaluation of the data, 8 mo storage at 135°F is approximately equal to 52 mo at 80°F; 16 mo at 110°F is approximately equivalent to 46 mo at 80°F.

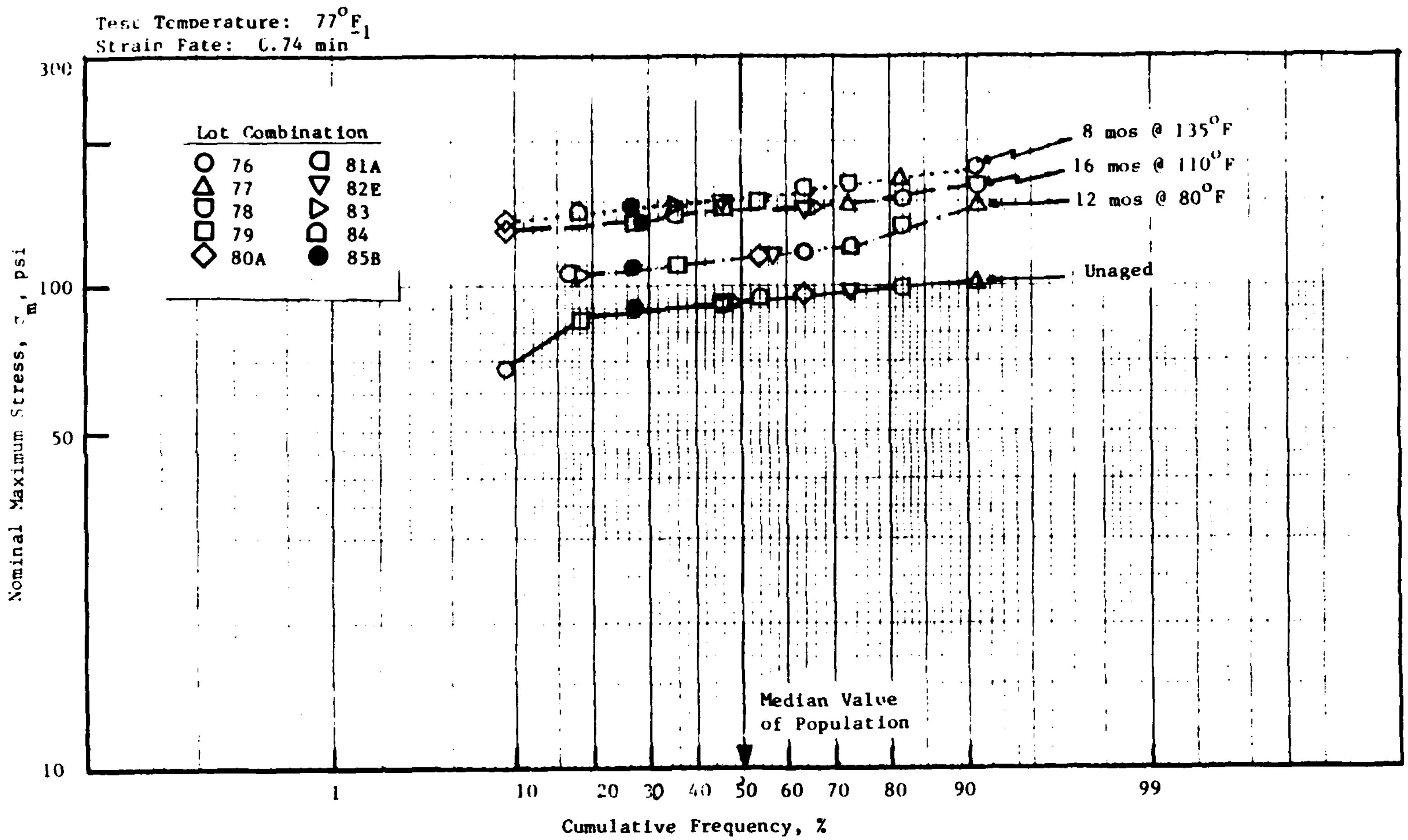


Figure 17. Effect of Aging on the Cumulative Frequency Distribution for Nominal Stress, ANB-3066 Propellant

Test Temperature: 77°F
Strain Rate: 0.74 min^{-1}

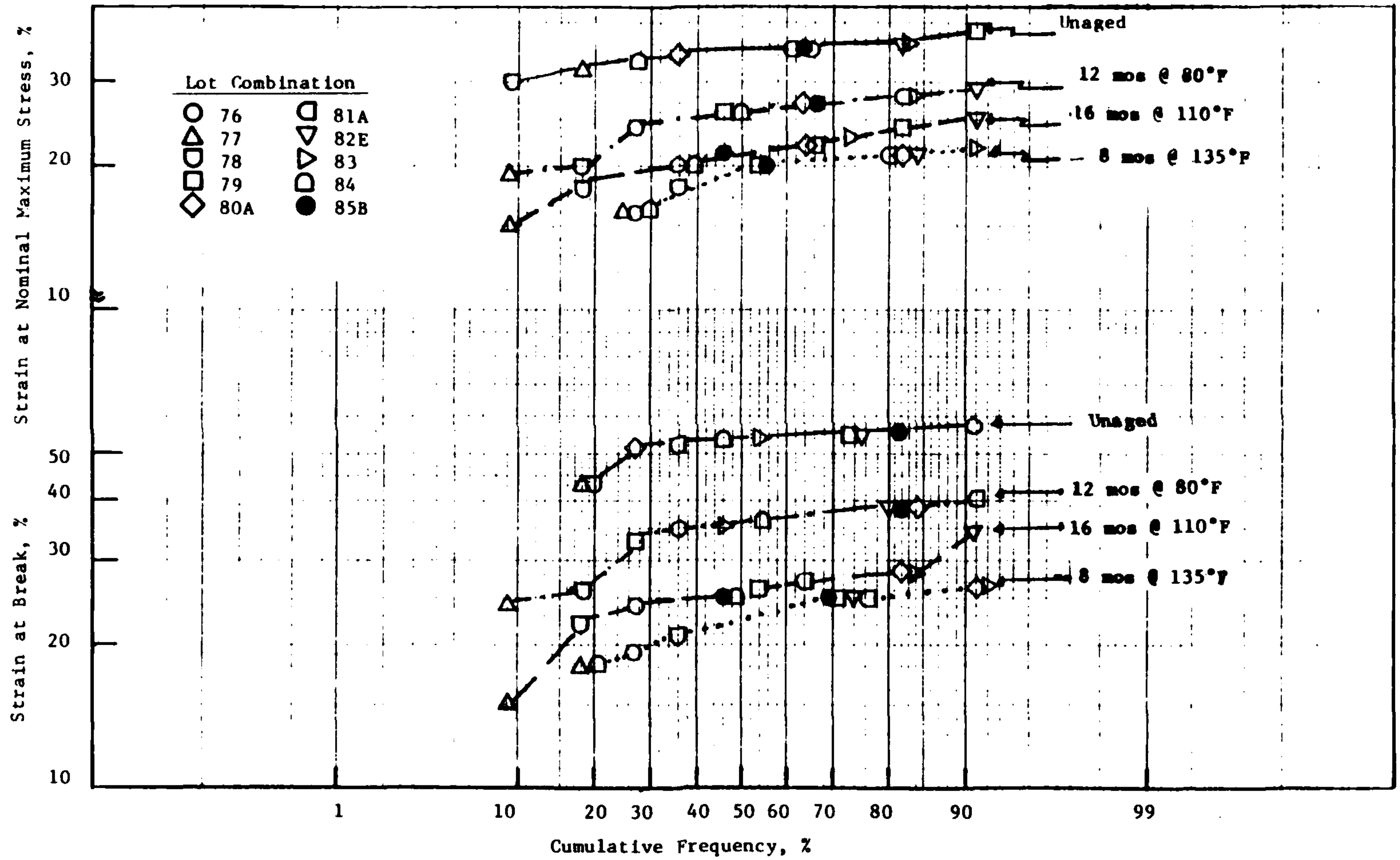


Figure 18. Effect of Aging on the Cumulative Frequency Distribution for Strain Capability of ANB-3066 Propellant

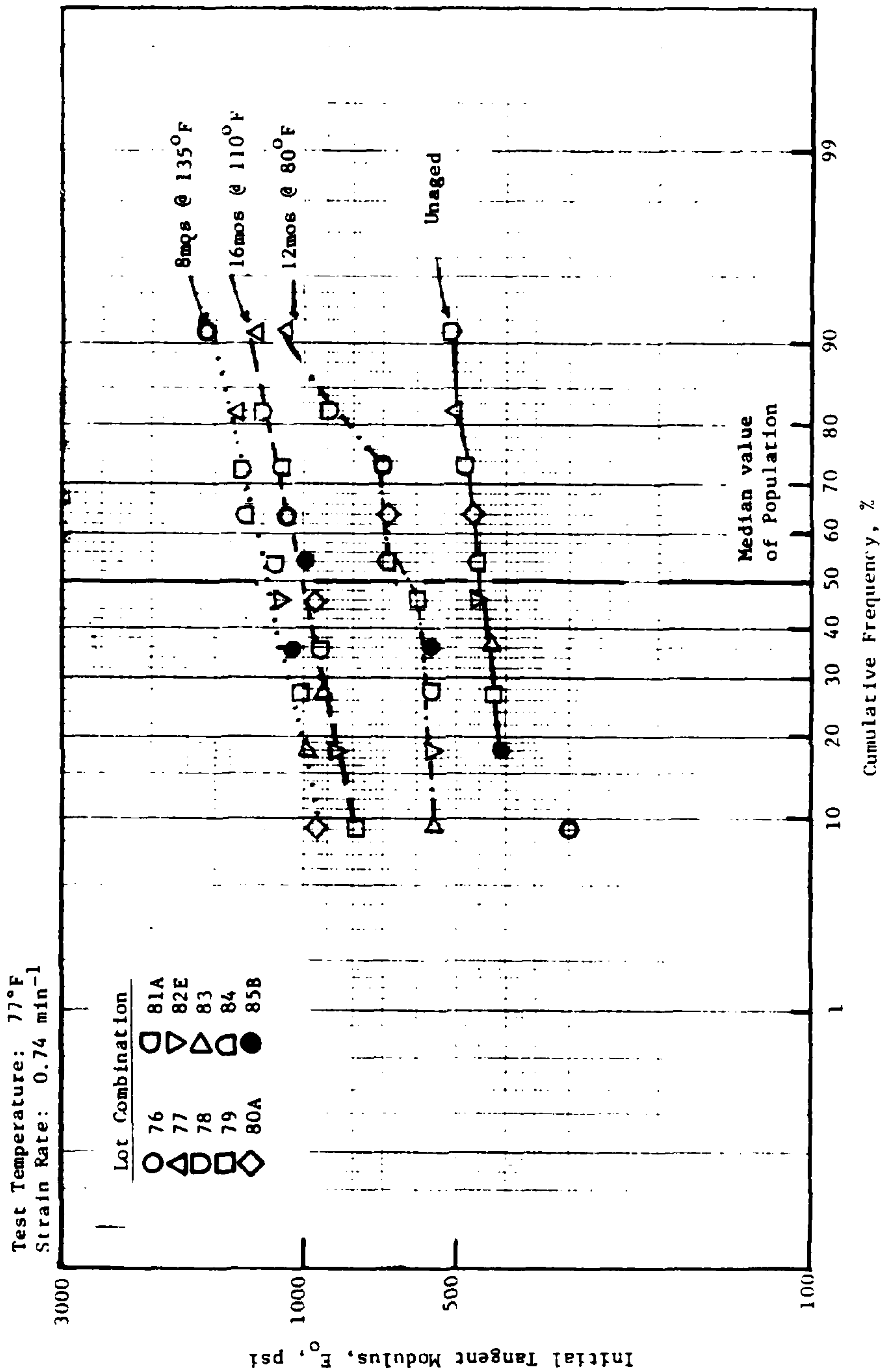
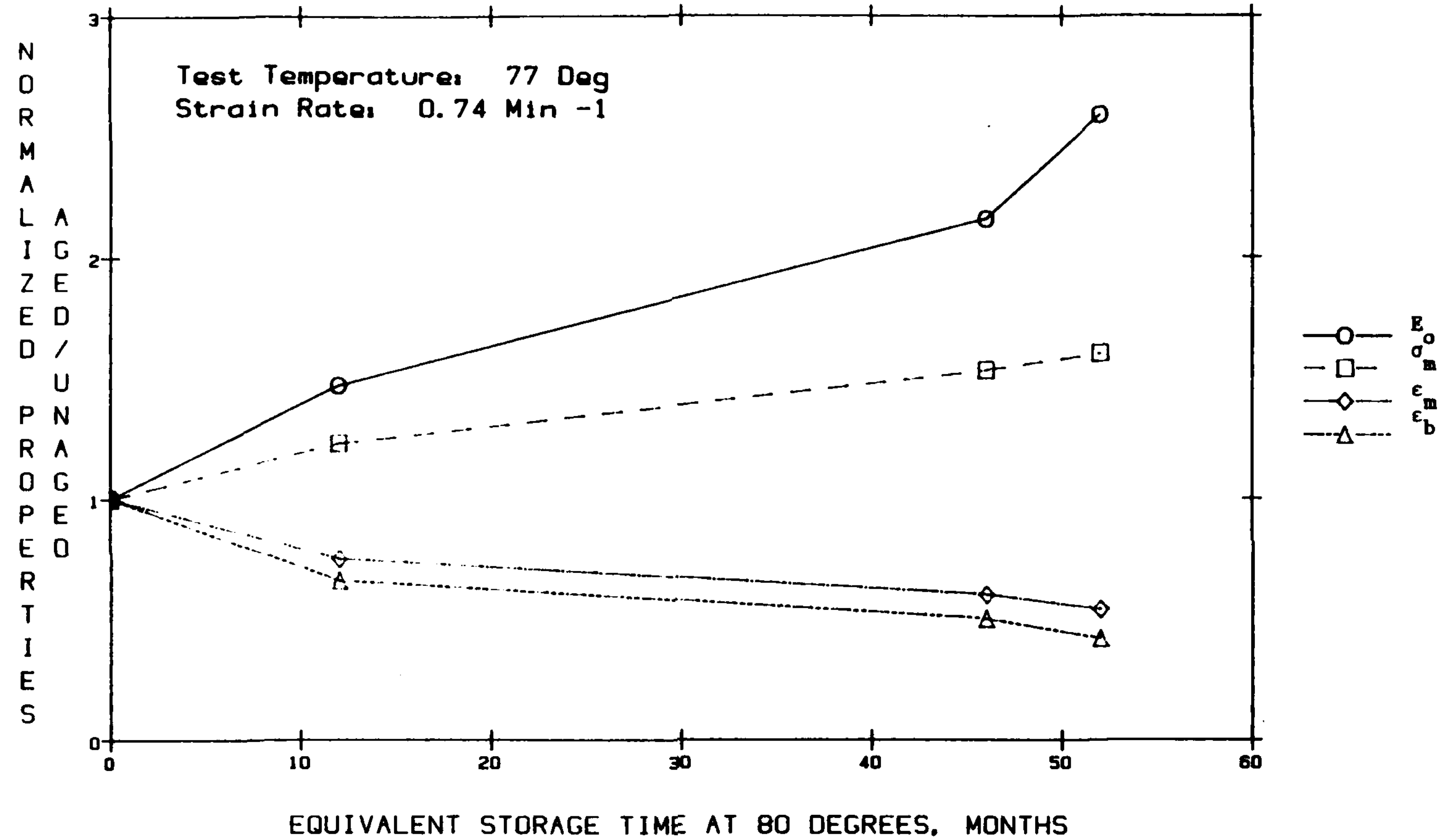


Figure 19. Effect of Aging on the Cumulative Frequency Distribution for Initial Tangent Modulus, ANB-3066 Propellant



BASED ON AN ACTIVATION ENERGY OF 12.0 KCAL/MOLE.
16 MOS AT 110 DEG = 46 MOS AT 80 DEG.
8 MOS AT 135 DEG = 52 MOS AT 80 DEG.

Figure 20. Effect of Aging on Normalized Properties for Lot Combinations of ANB-3066 Propellant

VI.B. Laboratory Samples (Cont)

(b) Stress Relaxation

Data for relaxation moduli (tests conducted at 77°F, 2.0% applied strain) of control and aged propellant samples are in agreement with hardening trends noted for uniaxial tensile properties.

Data were treated using the approach described for uniaxial tensile results (cumulative frequency distributions). The average (median) increase in relaxation modulus for the population (Lot Combinations 76 through 85B) following storage at several aging conditions is shown in the following table:

Aging Conditions	Median E_{r_1}	Normalized E_{r_1} (Aged/Unaged)
Unaged	263	1.00
12 mo at 80°F	450	1.71
16 mo at 110°F	680	2.58
8 mo at 135°F	790	3.00

A comparison of normalized relaxation modulus with normalized initial tangent modulus, Section VI.B.2.a.(1)(a), indicates a greater change in response properties with aging than in uniaxial tensile properties for samples stored at all conditions. Data are presented in Appendix B.

(2) Gradients from the Bore and Bondline

(a) Uniaxial Tensile Properties

Grain cracking due to propellant surface hardening has been identified as a potential failure mode for the Minuteman propellant-liner-insulation system (Reference 5). As a result, the gradients in uniaxial

VI.B. Laboratory Samples (Cont)

tensile properties as a function of distance from the simulated bore surface are routinely measured using mini tensile specimens (0.1 in. thickness, 1.0 in. gage length).

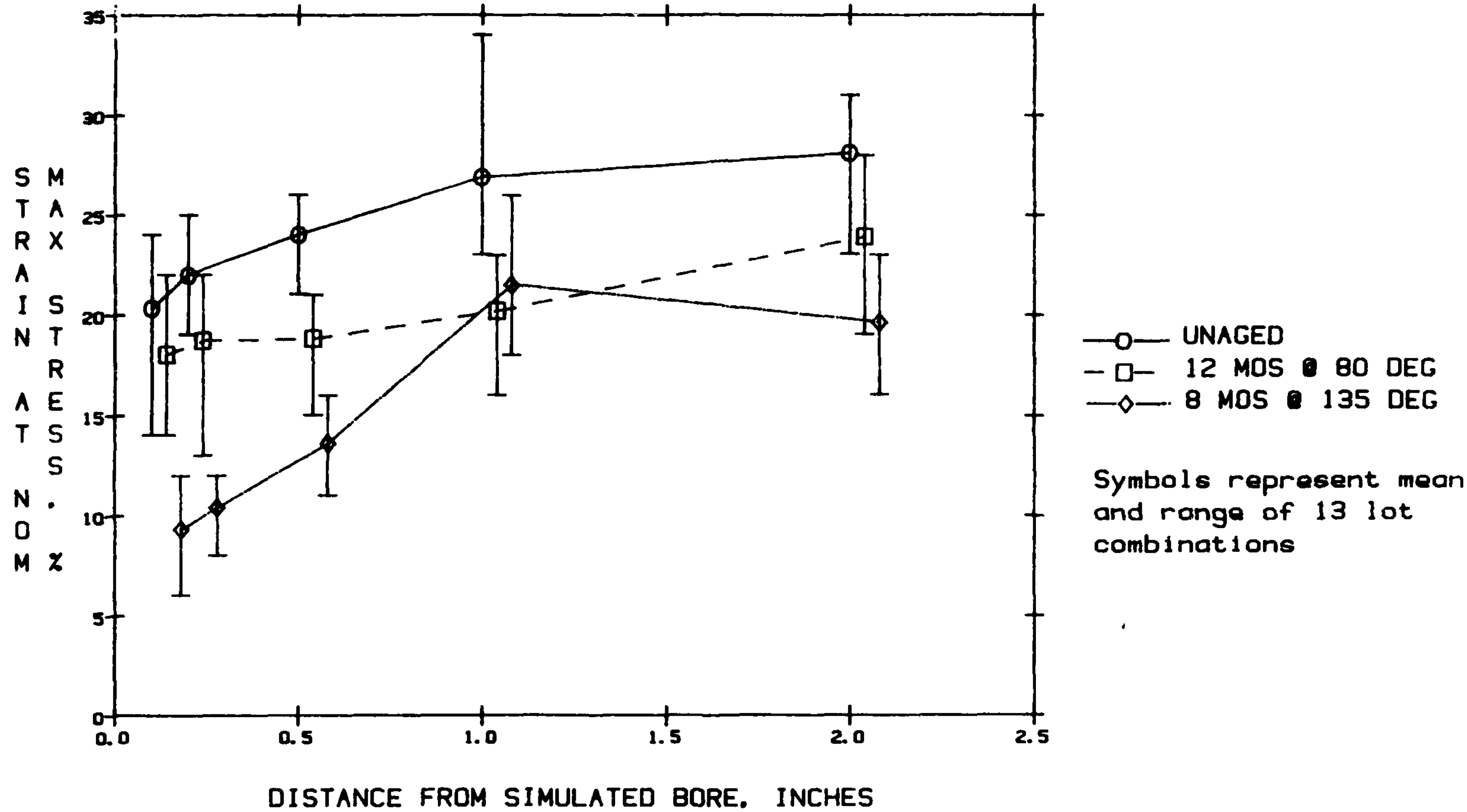
Effect of aging on strain capability at the bore surface for samples from 16 lot combinations (Lot Combinations 76 through 89) is presented in Figure 21. The most pronounced change in properties with aging (increased strength and modulus, decreased strain capability) occurs at the simulated bore surface (0 to 2.0 in. from bore surface). As expected, storage at 135°F produces most severe decreases in strain capability as shown in the following table:

Storage Conditions	No. Lot Combos	Average Ratio of ε_m* (Aged/Unaged): 0.1 in. from Bore Surface	Average Ratio of ε_m* (Aged/Unaged): 2.0 in. from Bore Surface
Unaged (ε_m Median)	16	20.8%	28.8%
Unaged	16	1.00	1.00
12 mo at 80°F	11	0.89	0.83
16 mo at 110°F	11	0.68	0.79
8 mo at 135°F	14	0.41	0.67

*Strain at Nominal Maximum Stress, ε_m

At distances greater than 2.0 in. from the bore surface, data indicate relatively uniform changes (on a percentage basis) throughout the analog; that is, the initial gradient in properties tends to be retained as the propellant is aged.

An exception is the propellant immediately adjacent to the bondline. A hardened layer is present in control samples at 0.1 in. from bondline interface. With additional aging, the propellant at 0.1 in. shows



Test Temperature: 77 Deg
Crosshead Rate: 1.0 in/min
Type Specimen: Mini Uniaxial Tensile

Figure 21. Effect of Distance From Simulated Bore on Strain Capability of ANB-3066 Propellant (Laboratory Samples)

VI.B. Laboratory Samples (Cont)

some softening, which has been attributed to migration and subsequent degradation of aziridines from SD-851-2 liner. Confirmed migration of plasticizers from the insulation may also contribute to propellant softening noted in aged samples.

Propellant at distances greater than 0.1 in. from the interface continues to harden with age.

Uniaxial tensile properties adjacent to the bondline are no longer measured. Changes in modulus, of particular concern at the bondline, are currently monitored using stress relaxation tests.

(b) Stress Relaxation

The gradient in relaxation moduli as a function of distance from the bondline was measured in tests conducted at 77°F with 2.0% applied strain. Data from 11 lot combinations have been combined with comparable uniaxial tensile data to provide a correlation between relaxation modulus and initial tangent modulus at the bondline (Figure 22). The correlation is significant for both the unaged population and for samples aged 8 mo at 135°F. The increase in slope* for the aged population indicates that relaxation modulus is increasing at a faster rate than initial tangent modulus for propellant adjacent to the bondline. This increase has also been noted for bulk propellant from laboratory samples [Section VI.B.2.a.(1)(b)]. The parameter E_{r_1} is important in assessing stresses at the bondline.

*Significant difference based on t-test, $\alpha = 0.05$.

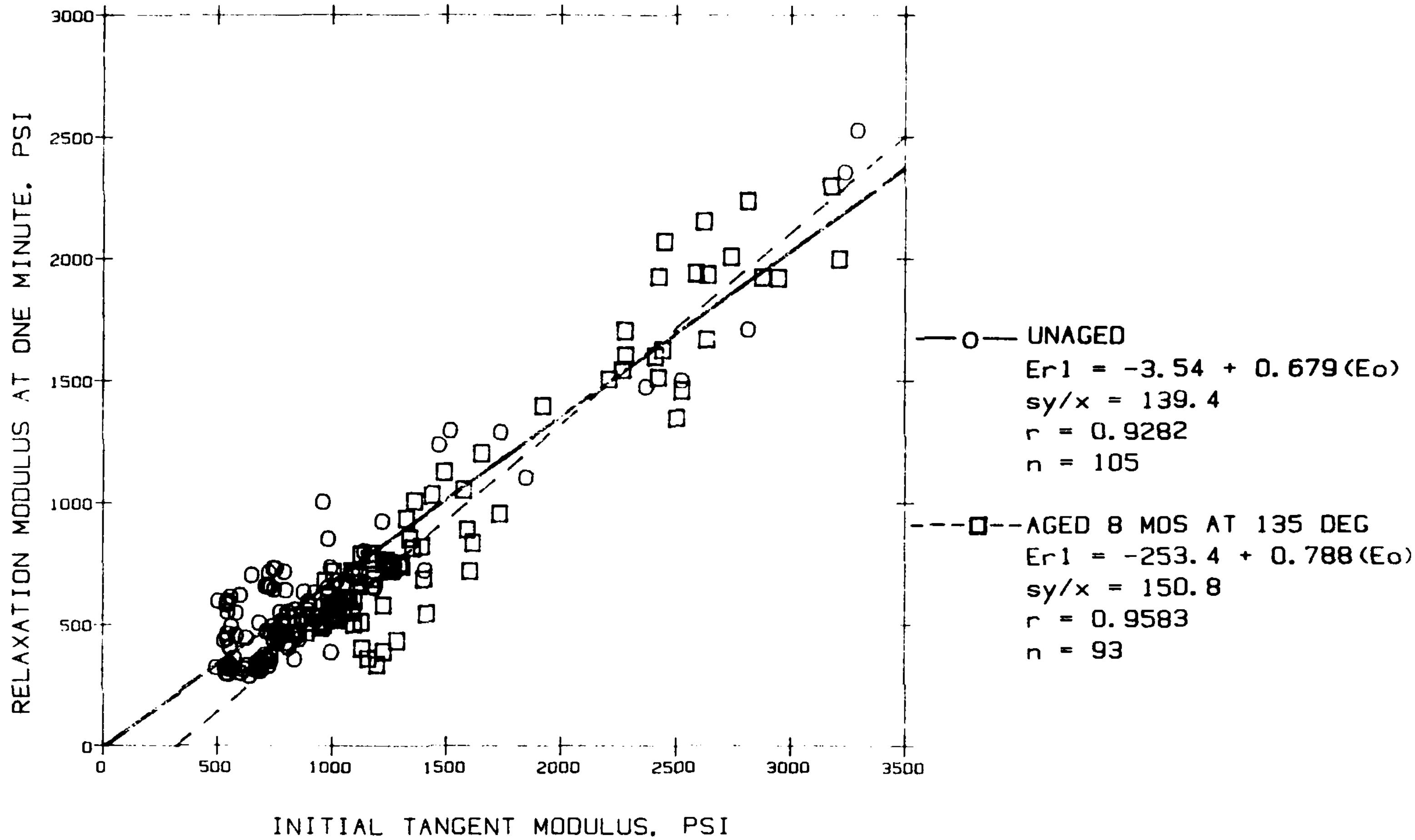


Figure 22. Relationship Between Relaxation Modulus at One Minute and Initial Tangent Modulus for ANB-3066 Propellant (Laboratory Samples, Control and Aged 8 mo at 135°)

VI.B. Laboratory Samples (Cont)

(c) Chemical Evaluation of Propellant by FTIR (Transmission Spectra of Chloroform Extracts)

Propellant extracts were analyzed by FTIR for gradients from the simulated bore and bondline surfaces of analog samples. The absorbance of the 970 WN peak (normalized to initial weight) exhibits changes typical of all CTPB peaks and is indicative of the amount of extractable CTPB. A complete discussion of FTIR capabilities is presented in SAAS-34. FTIR data is presented in Appendix B.

Gradient from the Bore - The decrease in extractable CTPB with aging near the bore surface is in agreement with the hardening observed for mechanical properties. The decrease in CTPB extracted after aging for 8 mo at 135°F is most pronounced to a depth of approximately 0.3 in. from the bore surface. Hardening to a similar depth is observed for mechanical properties. This hardening appears to be a result of oxidative crosslinking.

The wide range of extractable CTPB indicated for unaged samples from the various lot combinations is a result of the differences in the degree of post cure. After aging 8 mo at 135°F, the variability seen between the lot combinations has narrowed. However, the lot combinations having the least amount of extractable CTPB initially also have the least amount after aging (see Figure 23).

Gradient from the Bondline - The changes in the amount of extractable CTPB with aging near the bondline are in agreement with mechanical properties. The bondline interface initially has less extractable CTPB (compared to bulk propellant) due to the migration and subsequent reaction of the aziridines from the liner. The liner aziridines degrade thermally, which results in an increase in extractable CTPB after aging 8 mo at 135°F (see Figure 24). Similarly, mechanical properties show an initial hardness at the interface followed by softening.

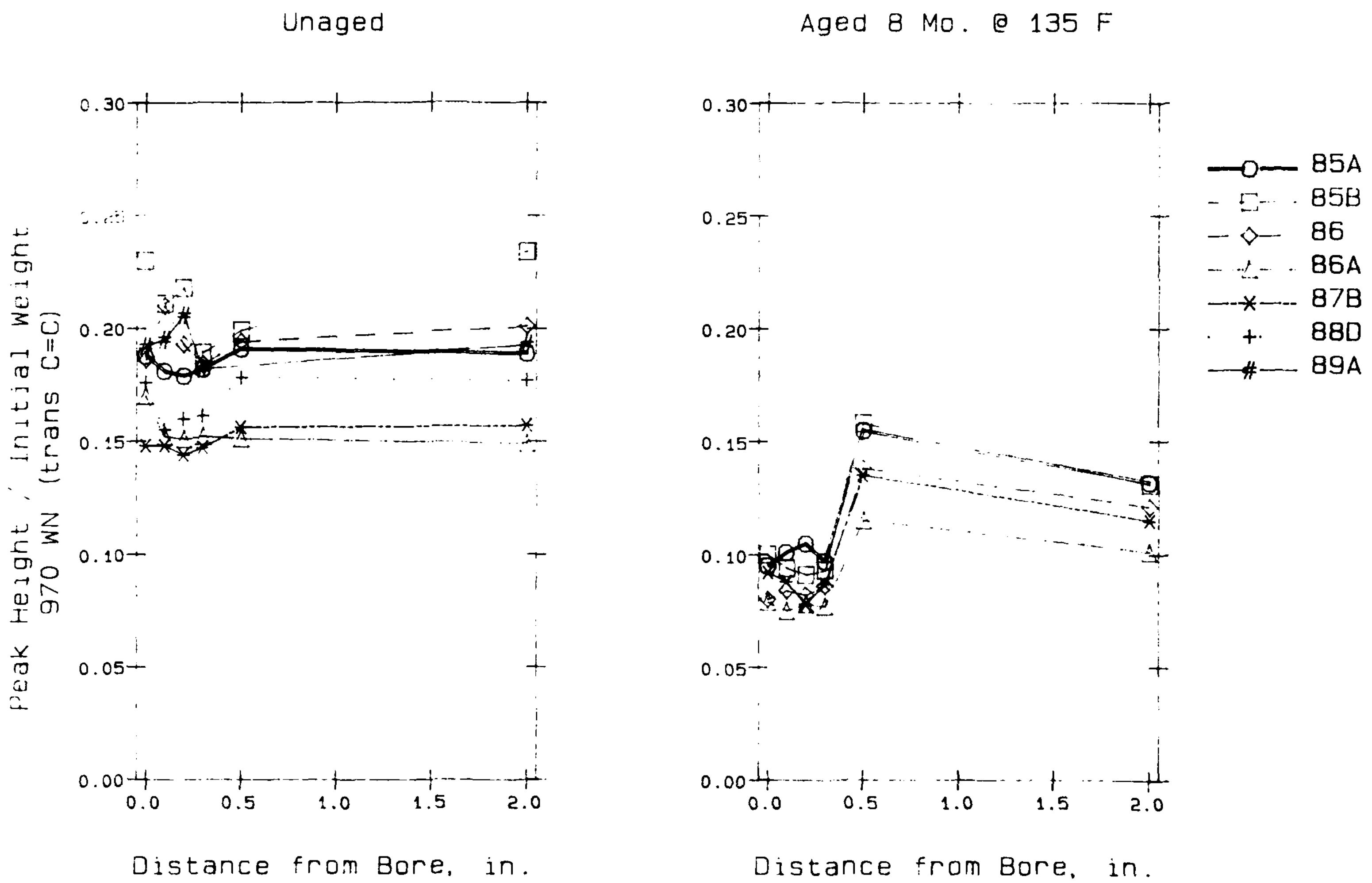


Figure 23. Bore Surface Hardening After Aging at 135°F Results in a Decrease in Extractable CTPB to 0.3 in., Indicated by a Decrease in Absorbance of 970 WN Peak (Normalized to Initial Weight)

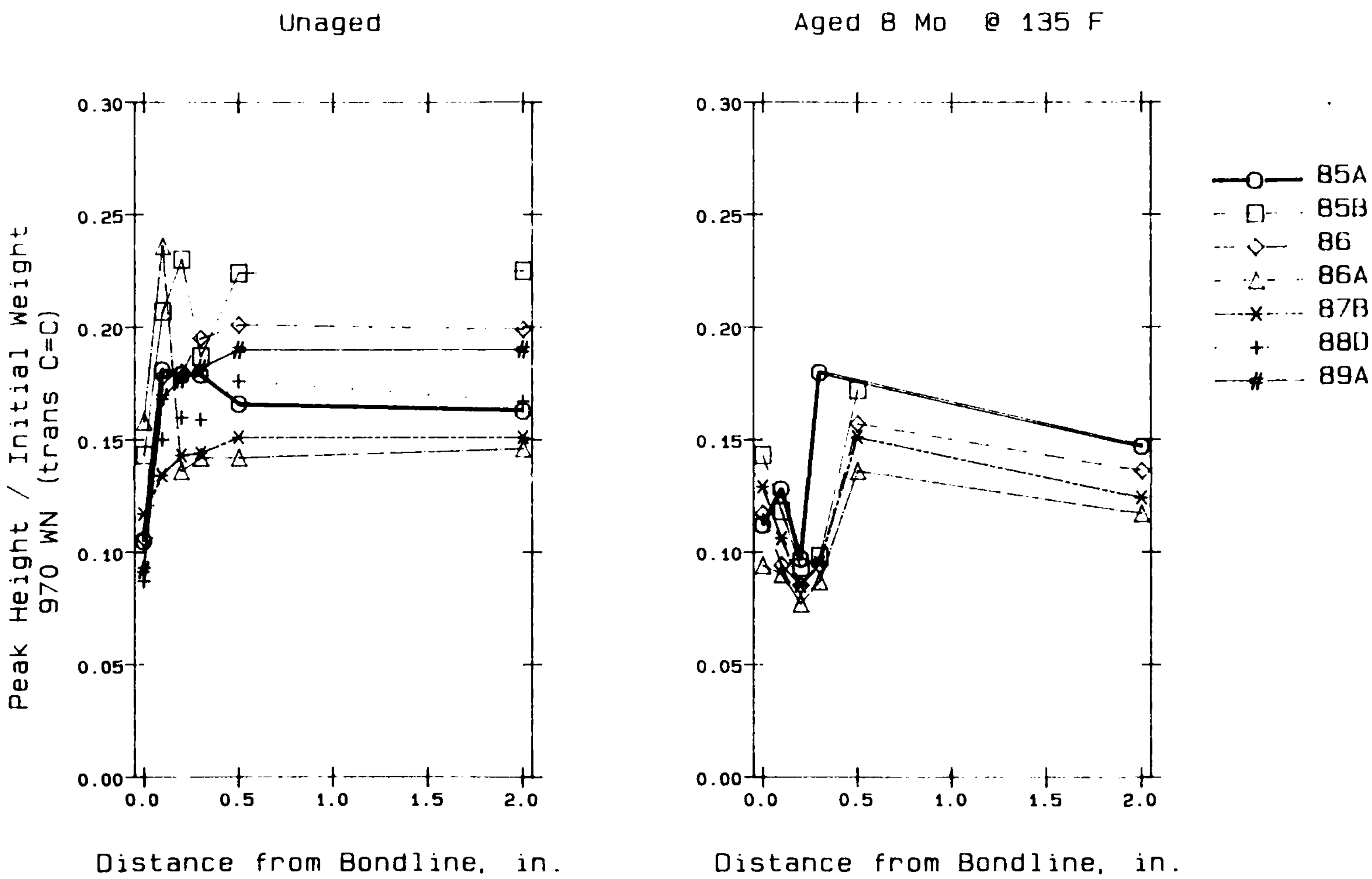


Figure 24. Amount of Extractable CTPB Decreases at All Locations with Aging Except at Bondline Interface, Increase in Amount of Extractable CTPB at the Interface Indicates Propellant Softening

VI.B. Laboratory Samples (Cont)

Propellant at distances greater than 0.1 in. from the bondline interface show a decrease in extractable CTPB with age, indicative of the hardening observed for mechanical properties.

Migration of DOP from the insulation into the propellant is monitored by increases in the absorbance of the peak at 1295 WN. After 8 mo aging at 135°F, DOP has migrated to a depth of approximately 0.5 in. from the bondline interface (see Figure 25). The effects of DOP plasticization of the propellant on mechanical properties cannot be defined since mechanical properties reflect the net results of plasticization (softening) and additional crosslinking (hardening).

b. Propellant-Liner-Insulation Bond

The effect of aging on the strength of the propellant-liner-insulation bond (ANB-3066/SD-851-2/V-45) has been routinely monitored using constant rate and constant load tests conducted at 77°F. These tests are now supplemented with high rate shear tests conducted at operational conditions (1,000 min^{-1}, 600 psig superimposed pressure) to determine effects of age on bond strength for firing. Although bond strength of the propellant-liner-insulation system is probably not associated with changes in propellant lot combinations, strengths are routinely monitored to provide general information regarding aging behavior of the bond.

Previous experience indicates that an initial increase in bond tensile strength is expected due to postcure. This increase is evident in results of constant rate tests for samples from most lot combinations stored at 80°F (Figure 26). (Data for Lot Combinations 79, 83 and 85B show a slight decrease for both standard and mini-sized specimens.)

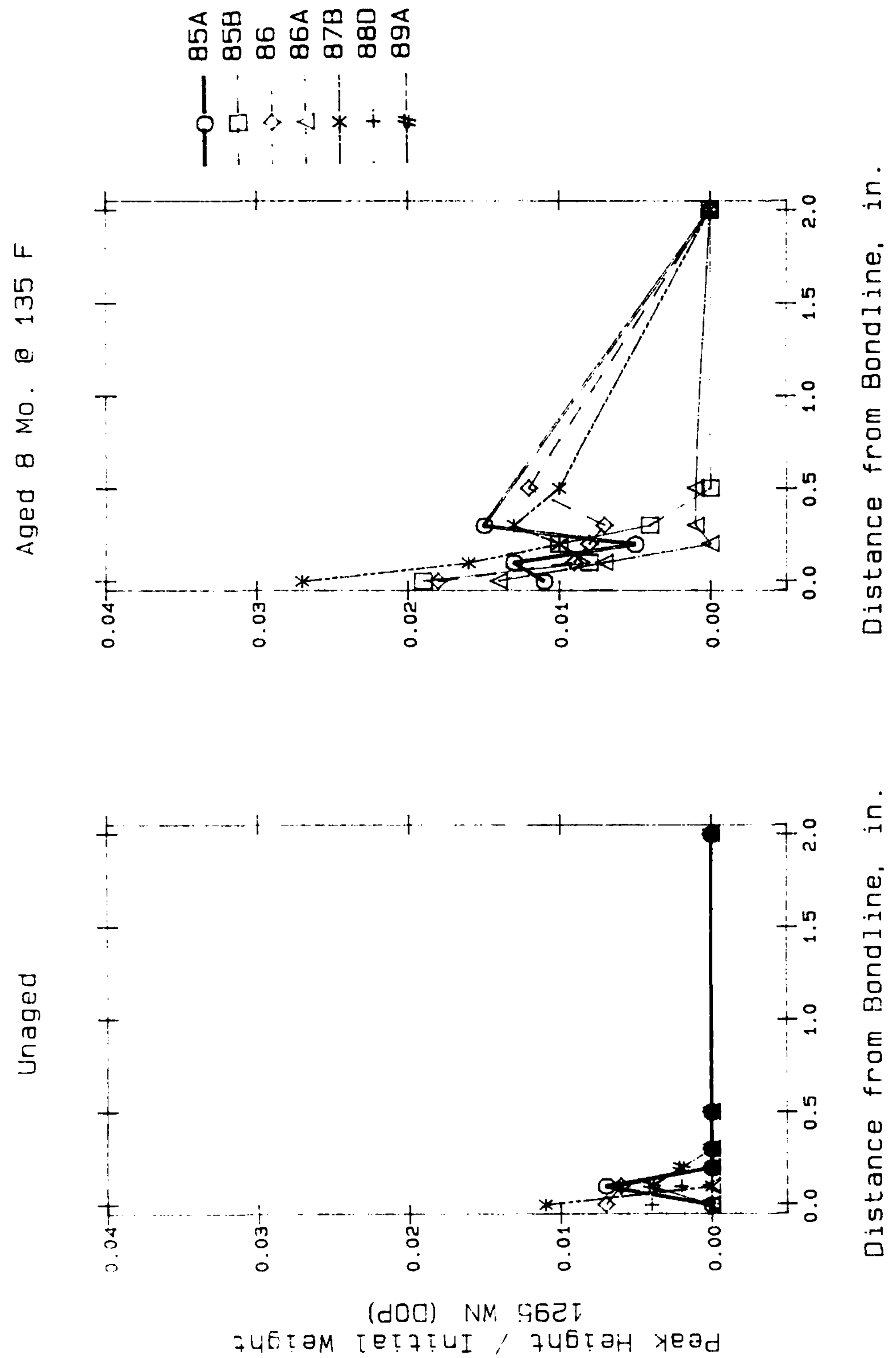
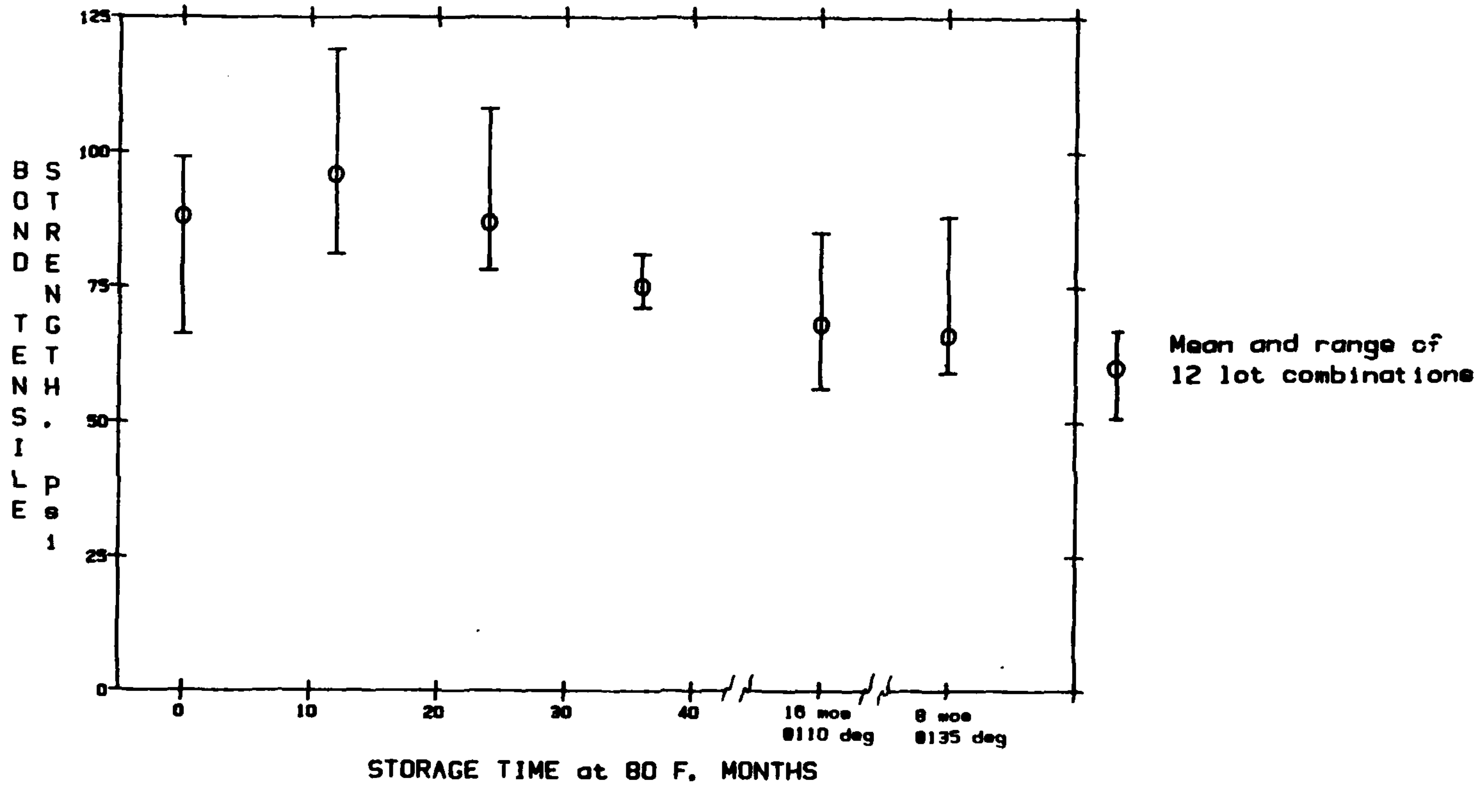


Figure 25. Migration of DOP From V-45 Insulation into the Propellant Occurs With Aging



Test Temperature: 77 Deg
Strain Rate: 1.0 min -1
Type Specimen: Double Plate Tensile

Figure 26. Effect of Aging on Bond Tensile Strength of ANB-3066/SD-851-2/V-45 Propellant-Liner-Insulation System (Analog Samples)

VI.B. Laboratory Samples (Cont)

Results from tests performed on samples stored for 24 or 36 mo at 80°F indicates a decrease in bond strength for all lot combinations. This decrease is expected, indicated by results of liner degradation studies conducted during the LRSLA program.

Results of constant rate tensile tests showed bond strength of samples stored at elevated temperature (110 or 135°F) decreases during the first year of storage for all lot combinations. Additional testing conducted on samples from Lot Combination 76 suggests that bond strength continues to decrease at elevated temperatures (tested following 24 mo storage at 110 or 135°F). Data for all lot combinations is provided in Appendix B.

Testing using mini-sized specimens (1.0 x 1.0 x 0.5 in.) has been performed in conjunction with standard specimens (1.75 x 1.75 x 1.0 in.). In general, bond tensile strength measured using mini-sized specimens is slightly lower than strengths for standard specimens over the range of data (40 to 120 psi). (A correlation relating mini and standard values was provided in the previous report.) Mini-sized specimens are frequently used where sampling material is limited (excised samples, plugs) or to evaluate effects of location in critical areas.

Results of constant load tests tend to be more variable than similar data from constant rate tests; however, results of constant load tests are valuable for evaluating long-term storage capability. Results of constant load tests for Lot Combinations 75 through 88D are provided in Appendix B. Tests were conducted at loads ranging from 19 to 70 psi with times to failure ranging to 253,514 min. (25 weeks).

Data are in general agreement with results of constant rate tensile tests in showing an initial increase in bond strength followed by decreasing bond strength for samples stored at 110 or 135°F.

VI.B. Laboratory Samples (Cont)

Tests of the propellant-liner-insulation bond have been expanded to include high rate shear tests conducted at operational conditions (tested at 77°F, 1,000 min^{-1}, 600 psig superimposed pressure). Values for unaged analogs from Lot Combinations 85A through 88D range from 220 to 272 psi. With aging, variability in strength increases: Of eight lot combinations for which aging data is available, three show increases and five show decreases in shear strength following storage at elevated temperatures (Figure 27).

On the basis of results from previous studies, no significant decrease in high rate shear stress is expected with increasing storage time (Reference 8).

The predominant mode of specimen failure continues to be either (a) within the liner, or (b) between propellant and liner (Reference 8).

c. SD-851-2 Liner

Updated data tables for chemical testing of SD-851-2 liner from Lot Combinations 76 to 89A are provided in Appendix B. Chemical testing includes swelling ratio and gel-filler fraction. Current data for lot combinations tested this report period follow previously established trends. Testing of liner will be continued to monitor deviations from established trends.

d. V-45 Insulation

Results of stress relaxation tests conducted on V-45 insulation from analog cartons stored at 80, 110 and 135°F are tabulated in Appendix B. The percent change in relaxation modulus at 1 min, E_{r_1} (tested at 77°F, 20% applied strain), for Lot Combinations 75 through 86 is as follows:

Test Temperature: 77°F

Crosshead Rate: 200 in./min

Superimposed Pressure: 600 psig

			Bond Shear Strength, psi following aging at:				
Lot Combo		Control	12 mo at 80°F	24 mo at 80°F	16 mo at 110°F	8 mo at 135°F	Aging Trend
80A				178			
82E			175		311		+
83			232		199		-
84			221			219	-
85A		220				243	+
85B		241	208		172		-
86		250				282	+
86A		272	222			170	-
87B		252				217	-
88D		253					
	$\bar{x}$	248	212	178	227	226	
	s	17.1	22.2	–	73.7	40.9	
	$s/\bar{x}$, %	6.9	10.5	–	32.4	18.1	
	n	6	5	1	3	5	

Figure 27. Effect of Storage Conditions on Bond Shear Strength of ANB-3066 Propellant/SD-851-2 Liner/V-45 Insulation Bond

VI.B. Laboratory Samples (Cont)

Change in Relaxation Modulus at One Minute, %

		Storage Conditions				
Lot Combo	E_{r1} at 77°F	12 mo at 80°F	24 mo at 80°F	36 mo at 85°F	16 mo at 110°F	8 mo at 135°F
76	1,086	-13	23	26	17	14
77	1,033	16			48	35
78	1,138	1	17	44	34	42
79	792	14	81		60	79
80A	870	20	-5		63	31
81A	810	-29				57
82E	990				32	43
83	874	26			84	42
84	790	17			73	37
85B	847	48			77	81
86	990					67
87A	1,215	36				19
87B	1,088					63
88D	1,294					
89A	1,162					

Comparison of insulation used in analogs with different propellant and liner lot combinations continue to indicate somewhat erratic data, probably due to orientation effects in the basic material. Unaged cartons representing Lot Combinations 76 through 86A gave values for relaxation modulus at 1 min. ranging from 790 to 1,294 psi. Relaxation moduli continue to show increase with increasing time and temperature at all storage conditions.

Chemical testing of V-45 insulation includes swelling ratio, gel-filler fraction, weight % DOP, weight % H_2O, Shore A hardness, and density. Updated data tables for chemical testing of insulation from Lot

VI.B. Laboratory Samples (Cont)

Combinations 76 to 89A are provided in Appendix B. Current data for the lot combinations tested this report period follow previously established trends. Complete testing of V-45 insulation in lot analogs will be continued to monitor any deviations from established trends.

C. SPECIAL TOPICS

1. Cracked Motor Investigation

a. Introduction

In support of the Aging and Surveillance program, propellant-liner-insulation samples are periodically removed from field-returned motors prior to remanufacture to assess effects of real-time aging for motors stored under actual silo conditions. As a result, Motor AA20629, returned for remanufacture 30 March 1985, was randomly selected for mechanical and chemical properties evaluation.

During routine nondestructive testing of Motor AA20629, a propellant crack was observed in the aft nozzle well area (270° orientation, forward of the aft equator, aft of the bore). In addition, surface irregularities (stippling) were noted in propellant aft of the crack. Motor AA20629, aged 198 mo, is the first of all returned motors in which a propellant crack has been observed.

This section summarizes results of work performed to determine age and cause of the crack and evaluate its effects on motor performance. A complete report, along with detailed test results, will be provided under separate cover (MMII-TP-018, Final Report).

VI.C. Special Topics (Cont)

b. Scope

Routine testing of field-returned motors encompasses:

- Visual inspection (to document physical characteristics of the motor).
- Mechanical and chemical testing of a propellant-liner-insulation sample excised from the aft end.
- Ignitability testing of a propellant sample excised from the forward end.
- Non-destructive testing (On-Surface Tester) at various locations within the bore to estimate mechanical properties of propellant in critical locations.

These tests were performed on Motor AA20629 for comparison with a database of samples from aged motors.

Subsequent to the crack discovery, the scope of testing was enlarged to determine cause of the crack and its effects on motor performance. Tasks included photographic documentation, X-ray evaluation, mechanical and chemical properties of samples from the affected area, as well as burning front, crack critically, and propellant stress analyses.

The location for various samples removed from Motor AA20629 is indicated in Figure 28. Tests were conducted according to the test matrix provided in Figure 29.

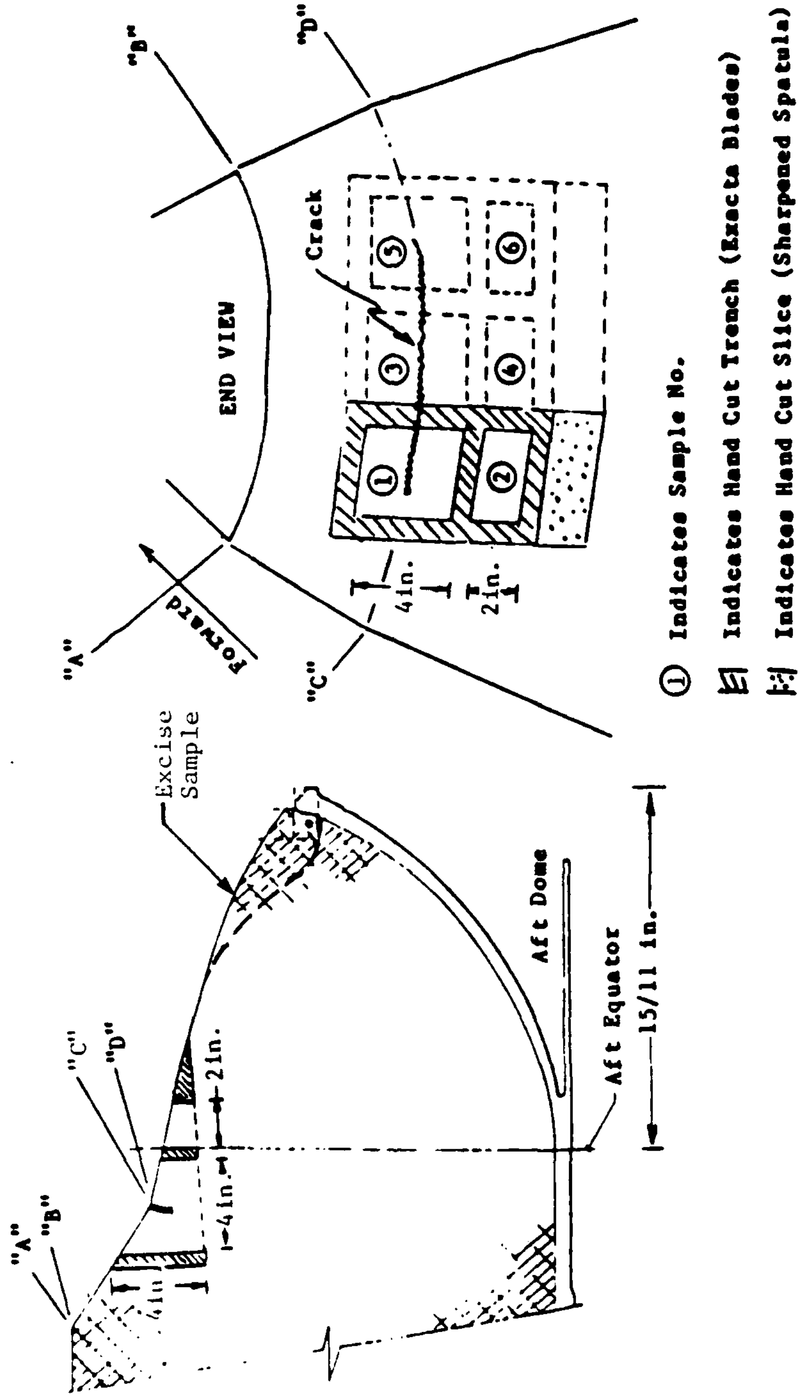


Figure 28. Location of Samples Removed From Crack Area Motor SN AA20629 Minuteman II, Stage II

Sample	Material	Test	Test Conditions Temp°F	X-Head	Location	Specimen Orientation
Aft Excise	Propellant	Mini S-E	77	1.0	Bore	Axial/Hoop
					Bond	Axial/Hoop
		Mini S-R	77	0.5/2.0%	Bond	Axial
	Bond	Double Plate Tensile	77	0.5	Bond	-
	Liner	Swelling Ratio Gel Filler Fraction				
	V-45 Insulation	S-R % DOP Gel Filler Fraction	77	1.0/2.0%		Hoop
Bulk	Propellant	S-E	77	2.0	Bulk	Axial
		Mini S-E	77	1.0	Bore	Axial
Crack	Propellant	Mini S-E	77	1.0	Bore (Aft of Crack)	Axial/Hoop
					Bore (Fwd of Crack)	Axial
					Bore (Fwd of Crack)	Axial
		Swelling Ratio Gel Filler Fraction FTIR				

Figure 29. Summary of Testing Conducted on Samples from Motor AA20629

VI.C. Special Topics (Cont)

c. Summary of Results

Results of the investigation indicate that the propellant crack was formed at the time of manufacture. This statement is supported by evidence from inspections under ultraviolet light and scanning electron microscope as well as mechanical and chemical properties evaluation of propellant samples from the affected area.

Ultraviolet Light (UV)

Upon examination under UV light, propellant near the bore surface typically exhibits discoloration bands. The discoloration results from diffusion of an environmental contaminant such as oxygen or moisture into the propellant. Examination of a propellant sample from the crack area indicated the presence of three bands (Figure 30). The shape of the bands from a cross-sectional view is significant: Each band interface is a uniform distance from the bore surface in the unaffected area. However, the bands extend deeper into the propellant surrounding the crack. Assuming constant diffusion rates from surfaces exposed to air, it appears the crack has been present for most of the life of the motor.

Scanning Electron Microscope (SEM)

Propellant from the affected area was examined under SEM to evlauate the surface conditions of the crack. Recrystallized ammonium perchlorate (AP) was identified along the surface of the crack in quantities similar to that found on bore surfaces. Newly exposed surfaces showed AP well contained within the propellant matrix. The presence of recrystallized AP on the crack surface could occur only following extended periods of exposure to moisture.

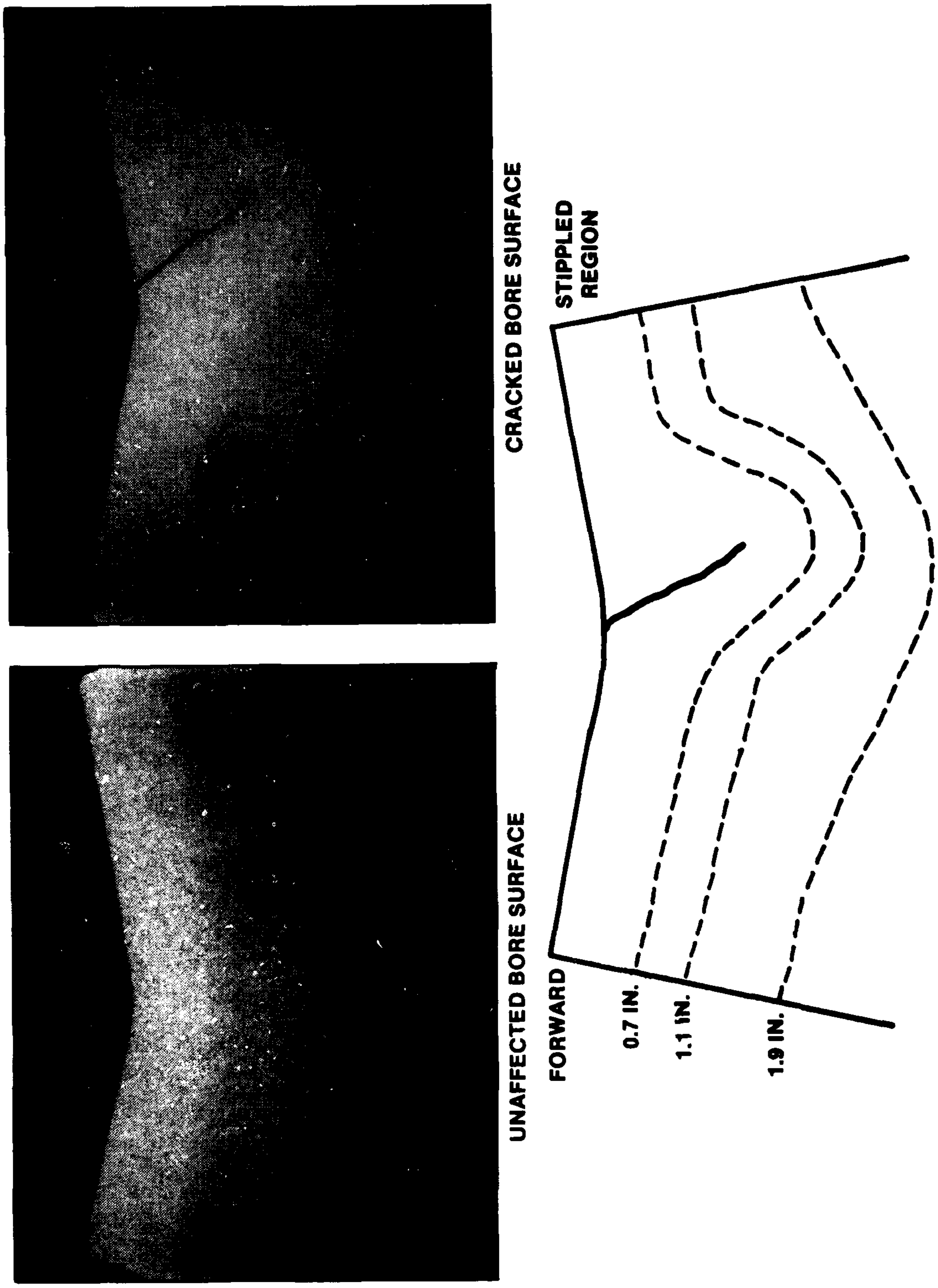


Figure 30. Ultraviolet Light Photos and Bond Color Plot

VI.C. Special Topics (Cont)

Mechanical Properties

Uniaxial tensile properties were measured as a function of distance from the bore surface for propellant removed immediately forward and aft of the propellant crack. Results confirm the presence of a hardened layer near the bore surface;* properties follow the visually observed contours of the crack.

Evaluation of additional propellant-liner-insulation samples removed for comparison with other aged motors indicate propellant from the cracked motor is typical of aged material from full-scale motors.

Chemical Properties

The trends observed in the chemical properties of the propellant are in agreement with the mechanical properties from a similar location. The hardening near the bore surface is supported by swelling ratio, gel-filler fraction and FTIR analysis.

Inspection and test results for Motor AA20629 are summarized in Figure 31. A scenario for grain cracking during manufacture is provided in Figure 32.

2. Investigation of Early Age-Out - Interim Progress Report

a. Introduction

The objectives of the study are to evaluate the aging condition of liner from motors considered to be prematurely aged and to investigate the potential causes for the observed condition. Tasks are:

*Hardening at the bore surface with age is expected for propellant formulated with Phillips CTPB

Task	Sample	Material	Tests	Conclusions
Motor History				
Production				No manufacturing anomalies
Operational				No abnormalities in silo histories or visual inspections of AA20629 or other motors from L.C.32.
X-Ray Inspection		Propellant		Original 1969 X-rays very poor quality; 1985 X-rays show crack.
Mechanical/ Chemical Evaluation	Excise (Aft End)	Propellant-Liner-Insulation	Mechanical/Chemical Properties	Typical aging behavior for material from AA20629 in comparison with aged motors
	Bulk (Aft Barrel)	Propellant	Mechanical Properties	Typical properties for comparably-aged motors. Good agreement in properties with those measured in excised sample (Aft end).
	Excise (Forward End)	Propellant	Ignitability	Ignition characteristics are normal
	Crack Sample	Propellant	Ultraviolet Light Inspection	Discoloration bands (attributed to diffusion of environmental contaminants from exposed surfaces) follow contour of crack. Indicates crack has been exposed for the life of the motor
			Scanning Electron Microscope Inspection	Presence of recrystallized ammonium perchlorate along crack (surface effect resulting from exposure to moisture) confirms crack surface is not recent
			Mechanical/Chemical Properties	Gradients in properties from bore confirm propellant hardening around the Properties follow visually observed contours around crack
			On-Surface Tester	Bore surface properties are typical of comparably-aged motors
Burn Front Analysis				Predict thermal motor ballistics
Crack Criticality Analysis				Low crack viscosity
Propellant Stress Analysis				Crack area in compression

Figure 31. Summary of Testing Conducted on Samples from Motor AA20629

The various events of the grain cracking process are:

1. The cast dam used in molding the grain in the nozzle well was not properly mold-released in the area around the 270 deg azimuth, except for the sprue hole.

2. After propellant cure, and while the grain was still at the cure temperature, the cast dam was pulled.

3. The mold-released area of the cast dam separated from the grain, while the unreleased area was still attached.

4. The eccentric load placed on the grain caused local nozzle well distortion and grain fracture at the stress concentration formed by the abrupt change in the bore configuration.

5. The grain fracture was subsurface, since the surface skin was still a high elongation rubber. This skin layer probably prevented early detection of the crack. Air oxidation of the surface polymer led to its fracture within a short time (less than a month).

6. The cast dam began to tear away from the propellant at this point. It removed some of the surface propellant leaving the grain with a stippled appearance.

7. Crack growth was probably limited to this initial event and motor cooling from the cure temperature. No detectable growth over time is indicated.

Figure 32. Scenario for Grain Cracking, Motor AA20629

VI.C. Special Topics (Cont)

- To perform mechanical, chemical, and nondestructive testing of materials excised from Motors AA21049 and AA21321.

- To review data and information from four sources:

  - previously issued technical reports
  - Hill Air Force Base motor carton testing
  - Aerojet archives
  - Integrated Processing Instruction (IPI) Log books

- To update the manufacturing variables study performed during LRSLA program

b. Scope/Status

This report summarizes results of:

- Testing conducted on samples removed from Motors AA21049 and AA21321

- Preliminary review of data from previously issued reports. Data includes test results of 113 motor excise samples, ranging in age from 44 to 222 mo, performed during both the LRSLA investigation and current service life analyses

- Preliminary review of results for testing conducted at Hill Air Force Base. Tests were performed through 1982 on cartons representing 36 motors, ranging in age from 17 to 90 mo (Reference 9)

VI.C. Special Topics (Cont)

- Preliminary update of the manufacturing variables study conducted during the LRSLA program (Reference 10).

c. Conclusions

On the basis of test data and visual inspection reports from ASPC, similar failure mechanisms are responsible for the rejection of Motors AA21049 and AA21321 from operational use. The probable cause for the premature age-out conditions, evidenced by excessive boot gap, is related to boot insulation shrinkage and to liner degradation. The degree of liner degradation is greater in Motor AA21321 than in Motor AA21049.

The large batch-to-batch variability observed in Hill Air Force Base testing of cartons implies that individual liner batches may be anomalous rather than all batches from an entire liner lot.

The preliminary assessment of the manufacturing variables study indicates that the rate of motor age-out may be predictable from the type of data documented in motor manufacturing supplemented by existing motor excised sampling data.

d. Background

Motors are visually inspected at OO-ALC during rotation from silos. On the basis of this inspection, motors can be rejected from operational use. A boot gap at the forward end of 0.03 in. or greater is the basis for closer inspection at OO-ALC. Motors are removed from the force if a boot gap of 0.06 to 0.12 in. is observed at the forward end, accompanied by degraded liner.

VI.C. Special Topics (Cont)

Boot gap is a result of boot shrinkage combined with liner degradation. Degree of boot gap has been hypothesized to be influenced by manufacturing variables, such as boot size and boot layup techniques. However, no permanent record of these variables is available to confirm the hypothesis. Boot shrinkage is related to the net loss of plasticizers in the V-45 insulation. The liner degrades via a hydrolytic reaction, therefore the rate of liner degradation depends on the moisture present in the bond system as well as motor age.

Six of the 37 motors visually inspected at OO-ALC since November 1983 have been rejected from operational use due to prematurely aged conditions (see the following table). These six motors range in age from 10 to 13 years and were cast using three liner lots; L_f, S_q, and Z_s* (liner lot Z_s was used during two time periods: Zs* 8/75-10/75 and Zs 12/75-1/77).

Two of the six motors, Motors AA21049 and AA1321, have been tested at ASPC. Samples from the remaining four motors will be removed and tested at ASPC during GFY 1986.

RESULTS OF MOTOR INSPECTIONS CONDUCTED AT OO-ALC

Motor SN	Strip Date	Liner Lot	Inspection Remarks
AA21046	10-1-72	L_f	0.090-in. gap, full 360 deg
AA21049	10-7-72	L_f	tacky liner
AA21058	10-25-72	L_f	liner flowing, 0.03-in. debond, 60 to 120 deg
AA21321	7-10-74	S_q	liner flowing
AA21434	9-28-75	Z_s*	tacky liner, 0.06 to 0.12-in. gap
AA21436	10-8-75	Z_s*	dark, tacky liner, 0.06-in. gap, full 360 deg

VI.C. Special Topics (Cont)

Three out of four motors with L_f, one out of two motors with S_q, and two out of four motors with Z_s* that were inspected were rejected for those liner lots.

e. Discussion

Motor AA21049 vs Motor AA21321

Similar failure mechanisms are responsible for the rejection of Motors AA21049 and AA21321 from operational use. The probable cause for the premature age-out conditions, evidenced by excessive boot gap, is related to boot insulation shrinkage and to degradation of the liner. Visual inspection reports by ASPC show a forward boot gap of 0.08 in. in AA21049 with tacky liner and a forward boot gap of 0.12 in. in Motor AA21321 with a flowing liner.

Mechanical and chemical testing of samples excised from the aft end of the motors support the observed differences in liner degradation between the two motors; Motor AA21321 has lower bond tensile strength, and a more highly degraded liner compared to Motor AA21049. Additionally, Motor AA21321 has softer propellant near the bondline, usually indicated in motors with degraded liners.

A comparison of test results is shown in Figure 33.

Testing conducted on a sample excised from the aft end of Motor AA21049 indicates that properties of insulation and propellant are within the ranges seen in comparably-aged motors. The dominant cause of the excessive boot gap in Motor AA21049 may be related to boot shrinkage or manufacturing variables affecting the boot insulation. Several processing variables have been suggested which may influence boot behavior (boot size, layup technique); however, no permanent records are available to verify the contribution of these variables.

	Test	AA21049	AA21321
Bond System	Bond Tensile	19 to 34, below average	12 to 27, below average
SD-851-2 Liner	Swelling Ratio	2.340	>2.5
	Gel-Filler Fraction	0.234	0.036
	FTIR	No New Peaks	No New Peaks
V-45 Insulation	Swelling Ratio	1.68	1.64
	Gel-Filler Fraction	0.889	0.891
	% DOP	1.46	1.59
	Relaxation Modulus, psi	2,246	1,961
ANB-3066 Propellant	Relaxation Modulus, psi	434 to 572, Typical	256 to 350, Soft; No Value Obtained at Bondline Interface
	Tensile Modulus, psi	Typical (bore)	Typical (bore)
	Tensile Modulus, psi	Typical (bondline)	Low Strength (bondline)
	FTIR	Not Available	High Concentration of Extract-ables at Bondline Interface
	Ignitability	Slightly Slower	Slightly Slower
	On-Surface Test	Typical	Soft

Figure 33. Summary of Test Results Motors AA21049 vs AA21321

VI.C. Special Topics (Cont)

Testing conducted on a sample excised from the aft end of Motor AA21321 indicates the liner is totally degraded at 138 months. Bond tensile strength of three specimens ranges from 12 to 27 psi; a value less than 20 psi is indicative of a totally degraded liner. The gel-filler fraction is 0.036; a value of 0.030 representing the filler content of the liner, indicates totally degraded liner. Propellant adjacent to the liner is also affected; both strength and strain capability are reduced at the interface.

Testing conducted at Hill Air Force Base on a 9 x 9 in. carton representing Motor AA21321 indicates that the liner was considerably degraded at age 67 months. Bond tensile strength was low (28 psi), gel-filler fraction was low (0.456), and swelling ratio was high (2.17) compared to average values obtained for cartons aged 60 to 80 mo (bond tensile of 44 psi, gel-filler fraction of 0.545, and swelling ratio of 1.94).

The combination of test results from ASPC and Hill Air Force Base indicate the liners from Motor AA21321 and the representative carton have either been degrading faster than normal or were marginal from the start. The initial condition of the liner used in the motor is unknown (see following discussion of batch-to-batch variability).

Properties of excised samples from Motors AA21049 and AA21321 are compared to excised samples previously tested at ASPC (Figures 34 to 36). Similarly, properties of cartons representing Motor AA21321 at 67 mo in comparison with cartons tested at Hill Air Force Base are shown in Figures 37 to 39. Test results for Motors AA21049 and AA21321 in addition to those for the population of motor excised samples tested to date are presented in Appendix A.

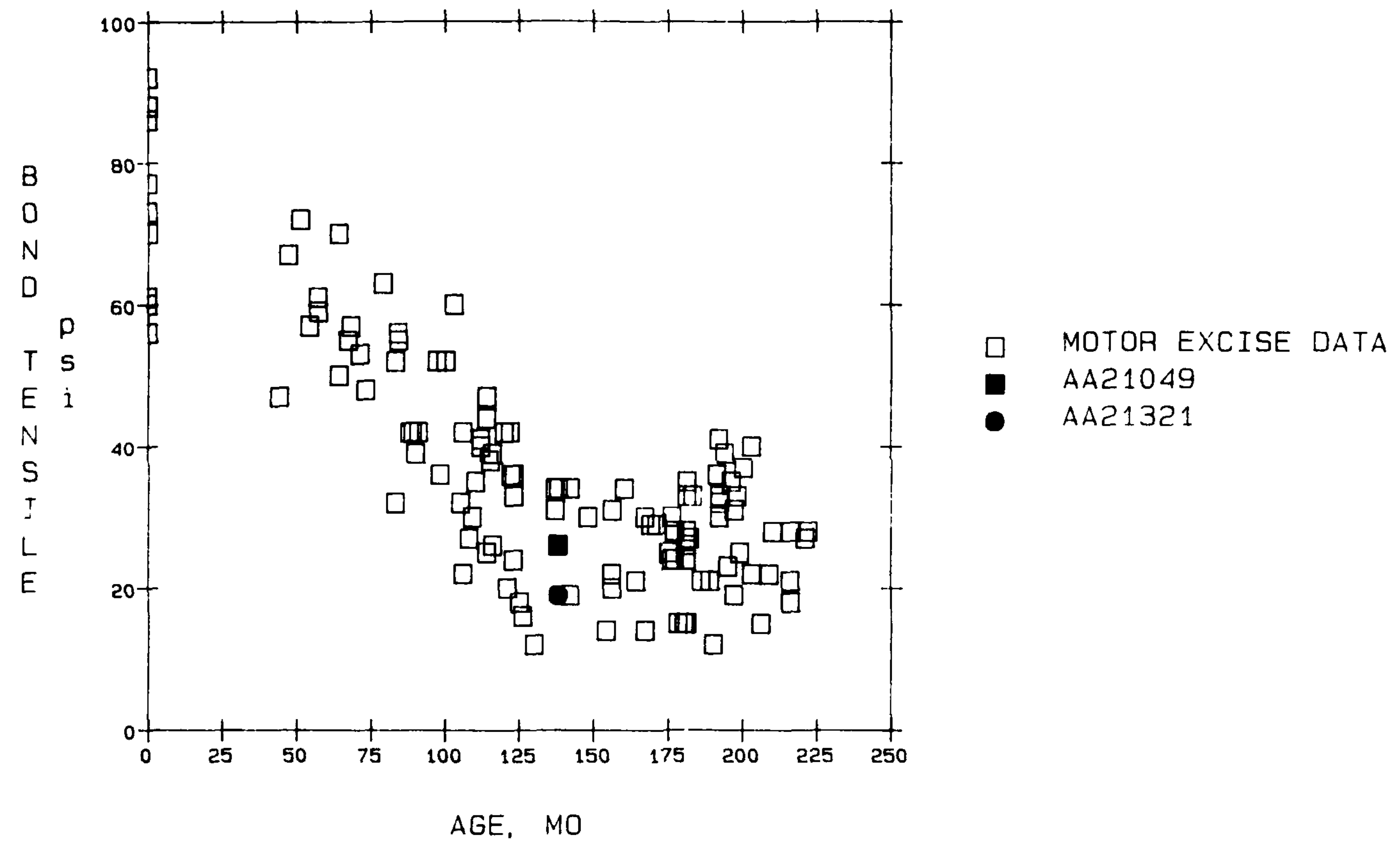


Figure 34. Bond Tensile Strength of Early Age-Out Motors
Compared to Other Excised Motors

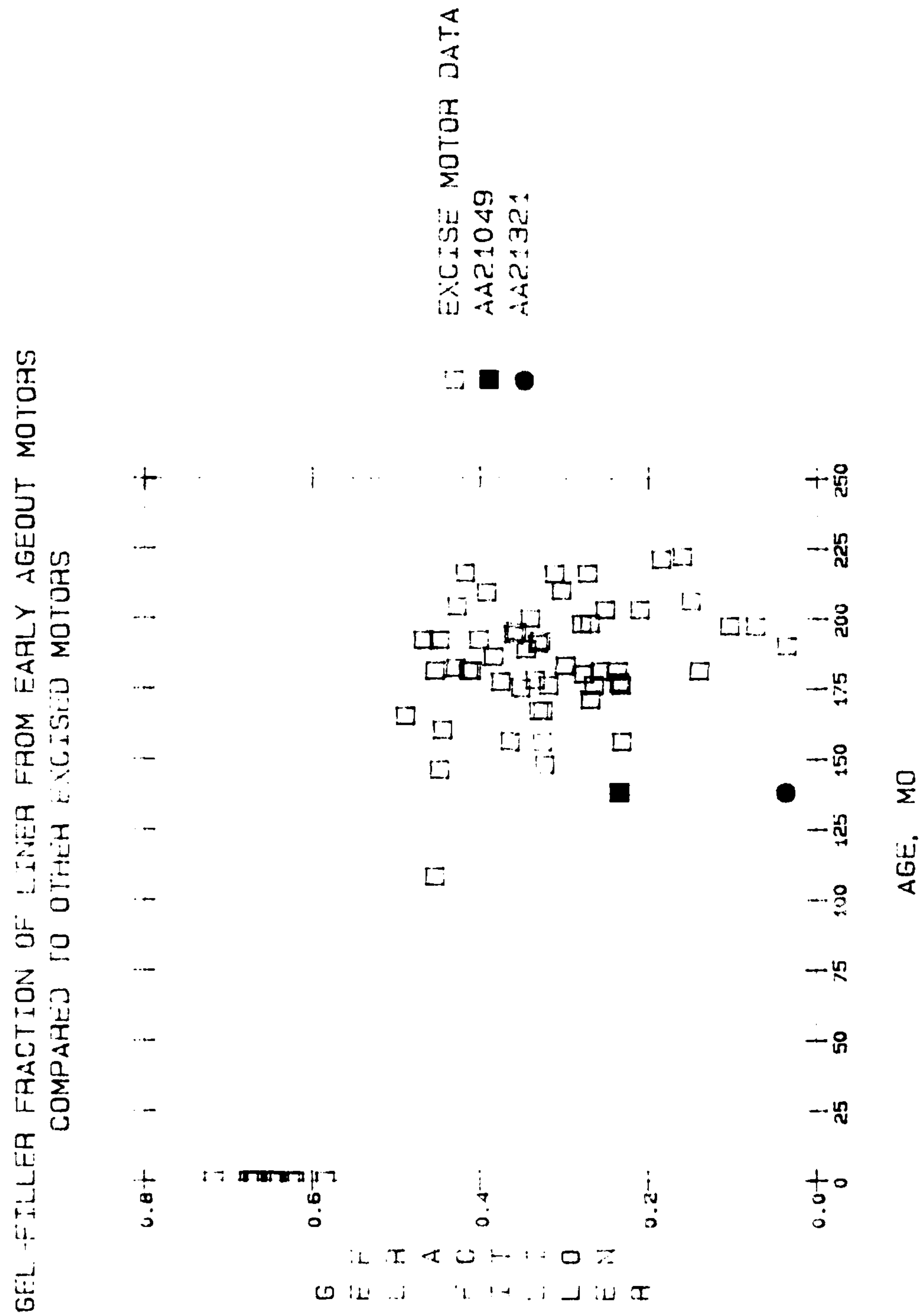


Figure 35. Gel-Filler Fraction of Liner From Early Ageout Motors Compared to Other Excised Motors

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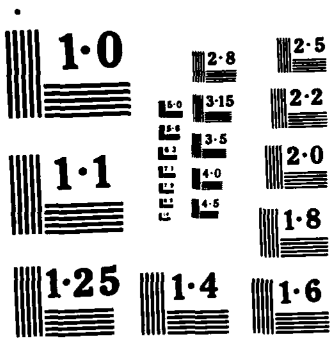


NATIONAL BUREAU OF STANDARDS
MICROCOPY RESOLUTION TEST CHART

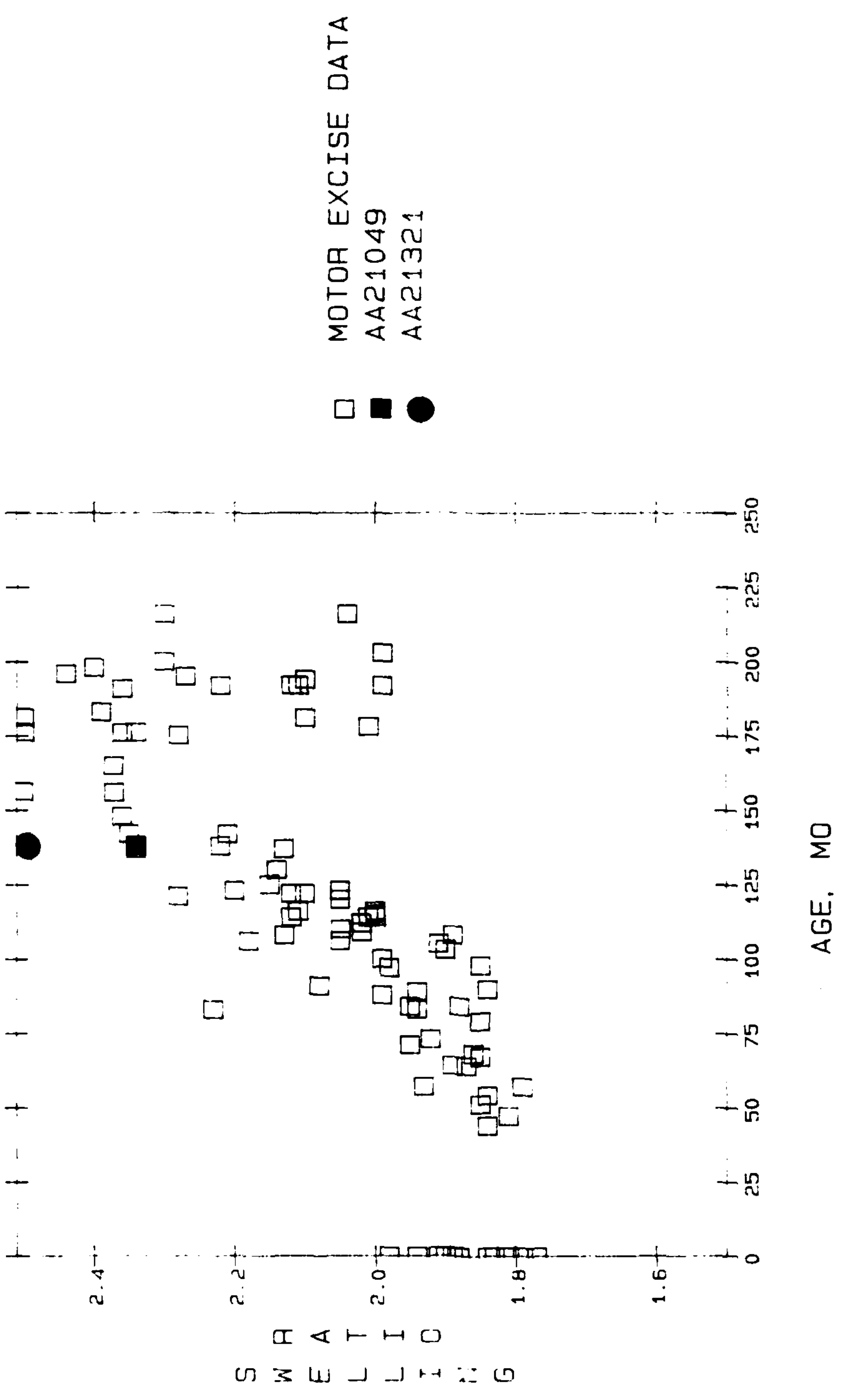


Figure 36. Swelling Ratio of Early Ageout Motors Compared to Other Excised Motors

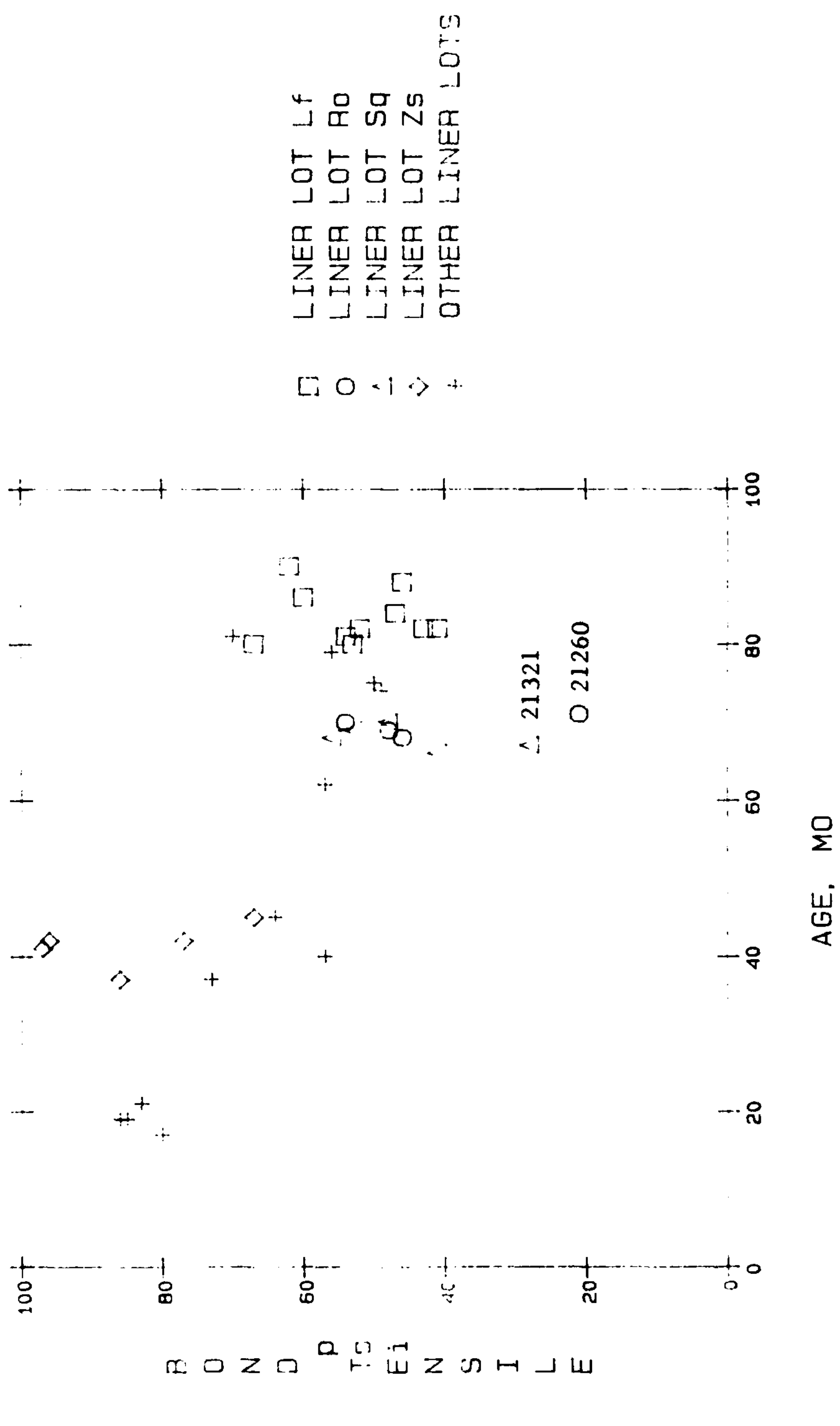


Figure 37. Batch Variability of Bond Tensile Strength Between Liner Lots

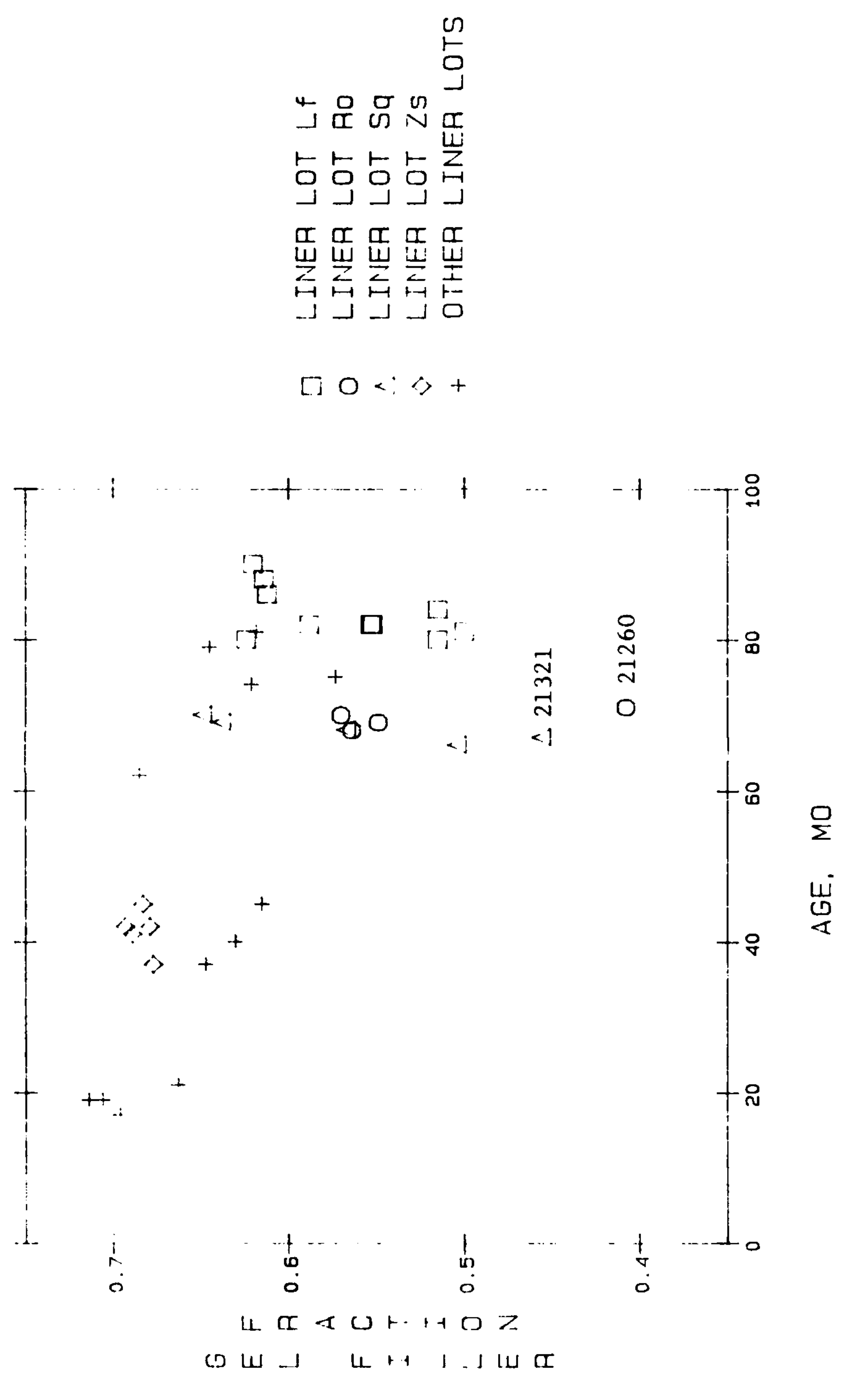


Figure 38. Batch Variability of Gel-Filler Fraction Between Liner Lots

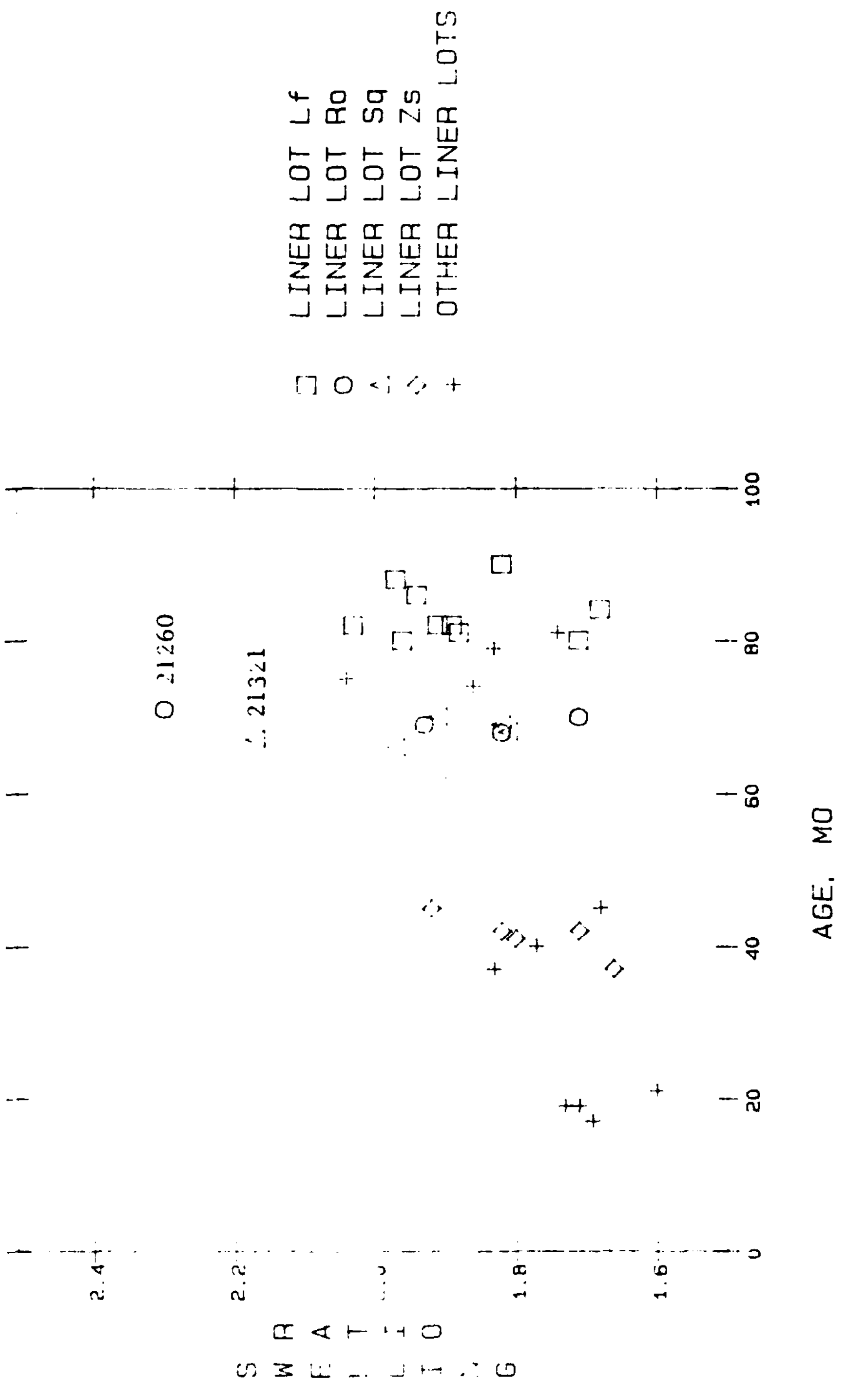


Figure 39. Batch Variability of Swelling Ratio Between Liner Lots

VI.C. Special Topics (Cont)

Batch-to-Batch Variability

Hill Air Force Base has been testing cartons cast from materials used in motors for several years. Bond test data is available from 36 cartons representing motors cast between 1972 and 1977. The age of the cartons at the time of testing ranges from 17 to 90 months. Test data for unaged cartons is not currently available. Testing included liner swelling ratio, liner gel-filler fraction, bond tensile strength (mini-DPT), and % insulation moisture.

Test data from Hill Air Force Base indicates large batch-to-batch variability within lots for the liner lots tested. Four liner lots were represented (n > 3) in the carton testing: Lf, Ro, Sq, and Zs. The ranges observed in three test properties are listed for each liner lot:

Liner Lot	Age, mo	N	Liner, Se/So	Liner Gel	Bond Tensile, psi
Lf	81 to 90	10	1.68 to 2.02	0.500 to 0.624	41 to 67
Ro	68 to 71	4	1.71 to 2.31	0.408 to 0.570	21 to 54
Sq	66 to 70	5	1.81 to 2.17	0.456 to 0.649	28 to 56
Zs	37 to 45	5	1.66 to 1.92	0.677 to 0.693	67 to 97

Out of the 36 cartons tested, 2 cartons are out of the observed range of values; the cartons representing Motors AA21321 and AA21260. The liner in AA21321 is from Lot Sq which has been identified as suspect. However, the liner in AA21260 is from Lot Ro which has not been identified as suspect (one motor with liner Lot Ro has been inspected and passed at OO-ALC). Further investigation of Motor AA21260 is recommended. The other cartons tested from these two liner lots are within the observed range of values.

These observations suggest that individual batches within a liner lot may be anomalous rather than an entire liner lot. Review of

VI.C. Special Topics (Cont)

additional data from Hill Air Force Base is necessary. No batch-to-batch variability is seen in testing conducted at ASPC since only one batch is routinely tested to qualify a liner lot. Graphic representations of the carton test data are shown in Figures 37 to 39. The test results are listed in Appendix A.

Preliminary Update of Manufacturing Variables Study

The rate of motor age-out appears to be predictable from the type of data documented in motor manufacturing, supplemented by age-dependent relationships derived from motor excised sampling data. The rate equation was derived on the basis of the conclusions reached in the initial manufacturing variables study conducted in 1976 as a part of the LRSLA program (Reference 10).

A large database was available for the initial study. These data included the manufacturing variables for the SD-851-2 liner for 1,347 Minuteman Stage II and 206 Minuteman Stage III production motors. In addition, excised sample data were obtained for 50 motors ranging in age from 44 to 130 months. In all, 67 variables were collected for each motor.

The studies reported in Reference 10 centered on the propellant-liner-boot bond strength as a function of motor age. Seven variables were identified as having significant influence on the boot bond strength:

- Initial Bond Tensile Strength (DPT), From Motor Sample Carton, psi
- Liner Premix Moisture Content, Weight %
- Delta Viscosity Buildup of Liner, Poise
- Liner Accelerated Cure, Rex Hardness
- Insulation Moisture Content, Weight %
- Liner Swelling Ratio Transform $[1000/(Se/So)^5]$
- Motor Age, Months

VI.C. Special Topics (Cont)

The initial bond tensile strength data is available from motor carton samples which were prepared for each motor only during the first three years (1965 to 1968) of the Minuteman Wing VI Production Program. For motors cast after 1968, the initial bond tensile strength is calculated from liner lot-combination qualification data (Reference 10). The excised sample data has been evaluated to derive age-dependent relationships for the insulation water content and for the liner swelling ratio transform (see Appendix D).

Visual motor inspections conducted through August 1985 were evaluated. Preliminary findings indicate GTR motors age-out at an earlier age than Phillips motors on the basis of nipple-propellant gap data (n = 31 motors from which excised samples were removed). Therefore, subsequent analyses are based on GT&R motors.

Multiple linear regression, using the seven variables listed above, results in an equation predicting nipple-propellant gap as a function of motor age. Incorporation of the relationships mentioned above results in an approximation of motor age-out using manufacturing variables only. The resulting age-out approximations can be ranked in ascending order of time-to-age-out (time to a specified nipple-propellant gap).

An "alert" value of 0.03 in. nipple-propellant gap has been established by OO-ALC to flag motors for further inspection. A motor age-out rate was calculated on the alert value and is compared to the actual age-out rate observed for GTR motors. (The actual age-out rate is calculated by the ratio of the cumulative number of motors exceeding the specified gap value to the cumulative number of motors inspected.) The observed rate curve lies to the right of the predicted rate curve; this is expected because the failed motors are inspected after they have passed the age at which the nipple-propellant gap just equalled the specified value (see Figure 40). See Appendix D for the motor early age-out prediction methodology.

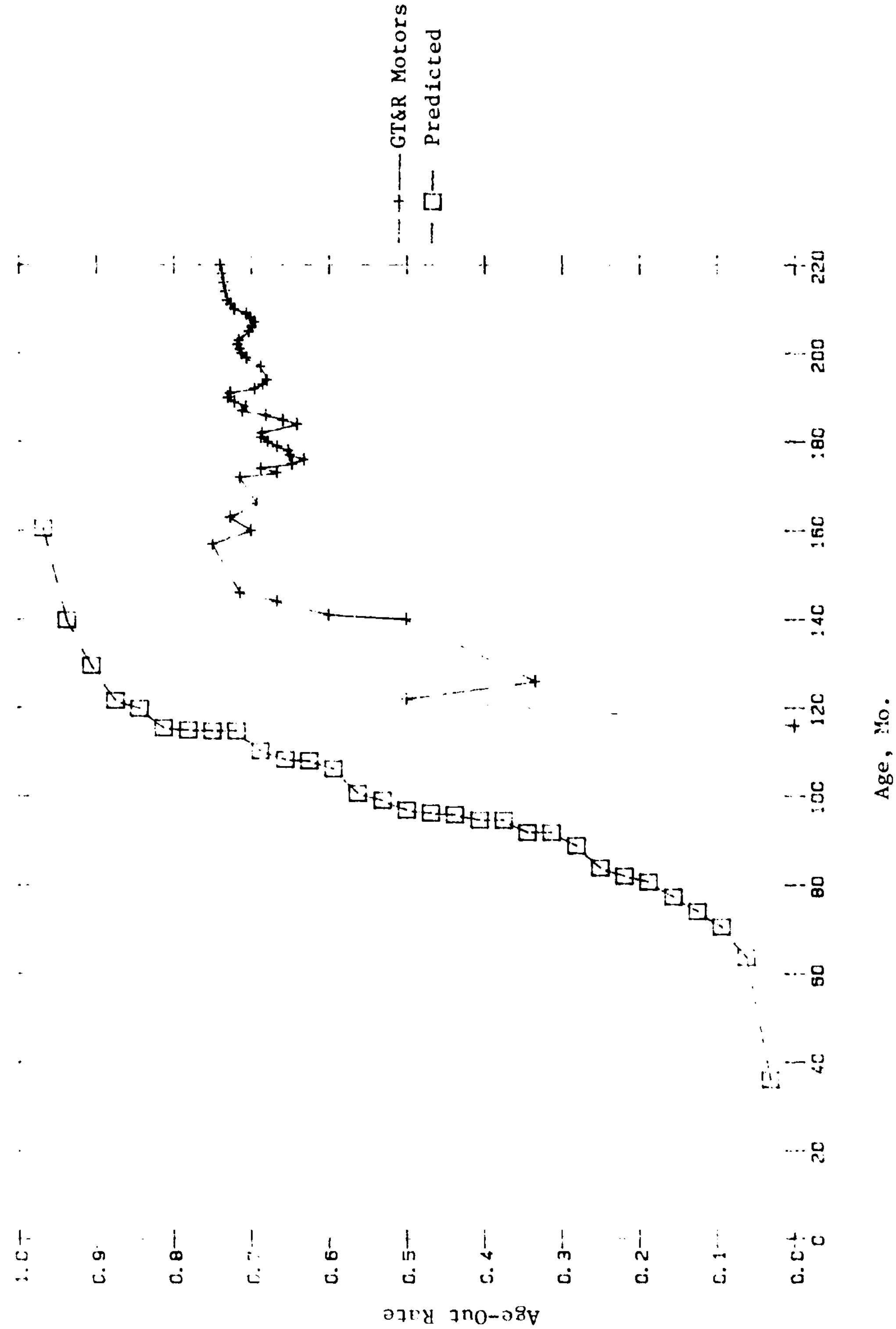


Figure 40. Predicted Age-Out Rate Compared to Observed Age-Out Rate

VI.C. Special Topics (Cont)

Subsequent evaluations of motor age-out rates will include calculations at various critical nipple-propellant gap values, will incorporate the motor data acquired from 58 motor excised samples tested between 1976 and the present, and will include evaluation of manufacturing variables from additional motors.

3. Plug Motor

a. Introduction

The concept of a plugged motor has been included in revised Test Plan, ATF-II-SLA-1. Periodic sampling of full-scale motors, stored under carefully monitored conditions, permits evaluation of aging trends in a realistic stress/strain environment without the complication of motor-to-motor variability. Methods have been developed to remove through-the-case samples (plugs include case, insulation, liner, and propellant) while retaining the structural integrity of the motor for future sampling (SAAS-34).

The program is designed to sample three motors (1976 vintage original manufacture, 1984- and 1986-vintage remanufacture) and evaluate them on a continuing basis for comparison with motors (and remnants of motors) of the same year of manufacture. Plugs from the forward, midbarrel, and aft chamber areas of each motor are supplemented with tests of excised samples (forward and aft), bore samples, and nondestructive test techniques.

Analog carton samples cast with the same propellant and liner batches used in the 1984 motor (MSEX-2) have been stored with the motor and will be tested in conjunction with the motor plugs at selected intervals to provide a correlation between material properties in the full-scale motor and corresponding properties of small-scale laboratory samples. Analog carton samples representing Motor 1986A will also be cast, stored, and tested as scheduled in Figure 41, thus providing additional motor-to-carton data. Knowledge of these relationships will enhance the value of the more economical analog samples.

Test Interval Years	0	0.5*	1	2	3	4	6	8	10	12	Total
. Plugs Tested											
Fwd Barrel	X	X	X		X	X	X		X	X	8
Mid Barrel	X(1)		X	X		X	X	X		X	8
Aft Barrel	X	X		X	X	X		X	X	X	8
. Excised Tested	X		X			X		X		X	5
. Bore Tested	X		X			X		X		X	5
. NDT Tests											
Bondline	X		X			X		X		X	5
Surface	X		X			X		X		X	5
Ignition Delay	X		X			X		X		X	5
. Analog Tests(2)	X(3)		X	X		X		X		X(3)	10
Ignition Delay	X(3)		X	X		X		X		X(3)	10

(1) 30 and 210° plugs

(2) Third batch only

(3) Three batches

* 1984, 1986A motors only

Figure 41. Test Schedule for Plugged Stage II Motor

VI.C. Special Topics (Cont)

b. Scope/Status

This discussion contains results of testing conducted on plug samples removed from the forward and aft ends of Motor MSEX-2 following 18 mo storage. Samples have been removed for the 24-mo test interval; results of testing conducted on two plugs, material from the aft end and aft bore, and a laboratory sample will be provided in the next report.

Initial samples have been removed from Motor AA21480, a 1976-vintage original-manufacture motor. This motor was selected for use as a plug motor to evaluate effects of real-time aging on mechanical propeties of late-production materials. Testing of plugs, excise and bore samples is in process.

c. Mechanical and Chemical Properties

(1) Bulk Propellant

(a) Uniaxial Tensile Properties

Bulk propellant from the forward and aft chamber areas continues to harden (as expected) with 6 mo additional aging (18 mo total). Initial tangent modulus, as measured at 77°F, 0.74 min^{-1}, increased slightly at both locations with corresponding decreases in strain capability. Strength of the propellant was not significantly affected by additional storage time.

	Forward Location					Aft Location				
Age, mo.	σ_m, psi	ϵ_m, %	ϵ_b, %	E_o, psi	SA	σ_m, psi	ϵ_m, %	ϵ_b, %	E_o, psi	SA
12	138	21	32	1,015	57	131	18	31	1,267	61
18	135	20	29	1,160	61	135	16	27	1,369	63

VI.C. Special Topics (Cont)

Data suggest that propellant in the aft chamber is slightly harder than material removed from the forward chamber. Differences in properties due to sample location will be evaluated following 24-mo testing.

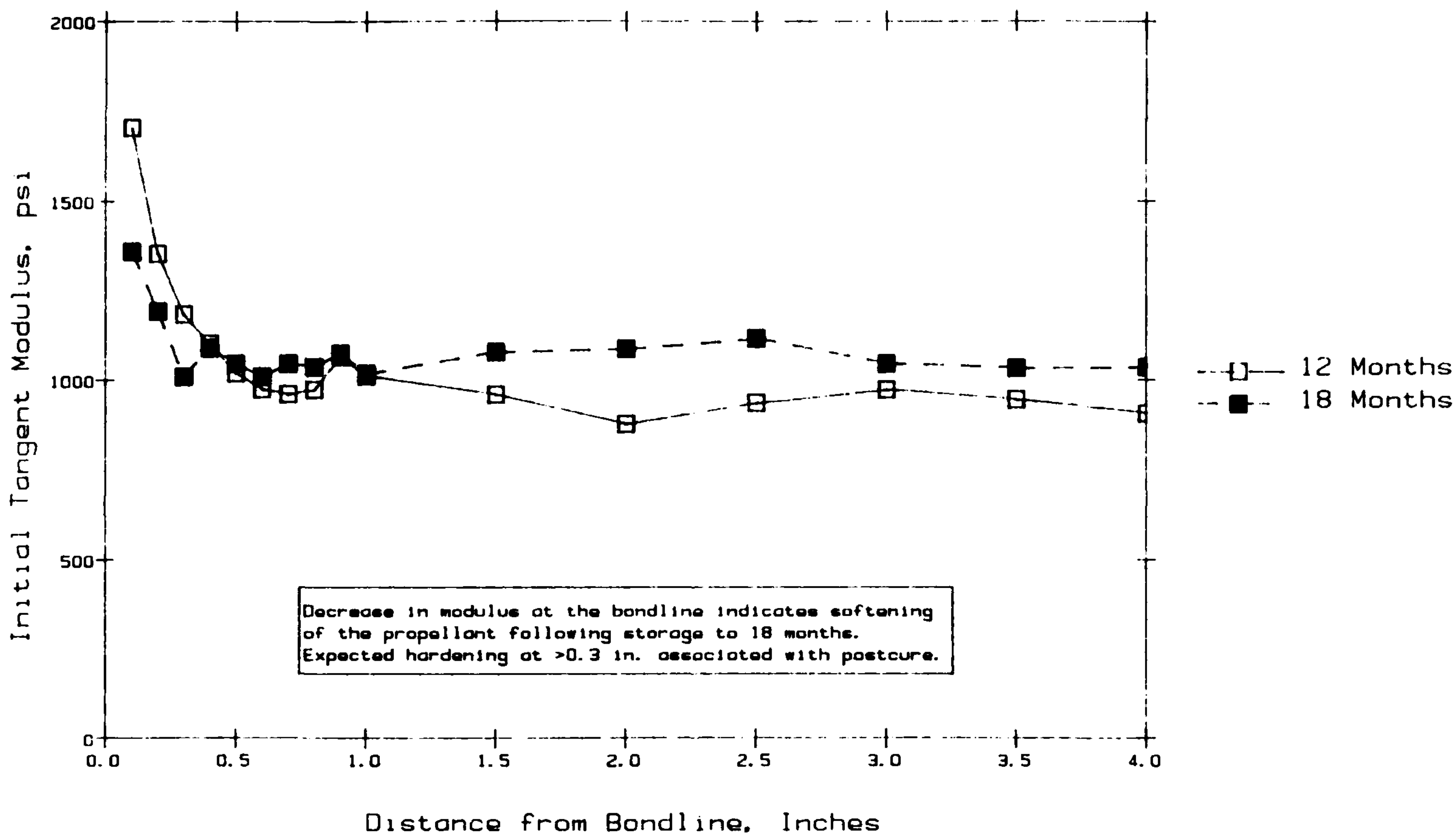
(b) Stress Relaxation

Results of stress relaxation tests support trends noted for uniaxial tensile properties. Testing was conducted at 77°F with 2.0% applied strain.

(2) Gradient from the Bondline

(a) Uniaxial Tensile Properties

Changes in modulus with aging are of particular concern at the bondline of motor, where stresses are greatest. As a result, the gradients in uniaxial tensile properties as a function of distance from the bondline interface were measured in plug samples using mini-tensile specimens (0.1-in. thickness, 1.0-in. gage length). Results of testing conducted at 77°F, 1.0 min^{-1} are plotted in Figure 42. Data indicate that propellant near the bondline interface has softened with 6 mo additional aging. Both propellant strength and modulus values have decreased from 0.1 to 0.5 in. from the interface in comparison with 12-mo values. Strain capability remains unchanged. Propellant at distances greater than 0.5 in. from the interface continues to harden, as previously noted for bulk propellant [Section VI.C.3.c. (1)]. Softening at the bondline has been identified in laboratory analogs stored at elevated temperatures, and is attributed to species migration from the liner and insulation. Data are tabulated in Appendix A.



Sample Location: Forward Plug
Test Temperature: 77 Deg
Strain Rate: 1.0 Min -1

Figure 42. Effect of Age and Distance From the Bondline on Uniaxial Tensile Properties of Samples From Motor MSEX-2

VI.C. Special Topics (Cont)

(b) Stress Relaxation

Gradients in relaxation moduli as functions of distance from the bondline of plug samples were measured in tests conducted at 77°F with 2.0% applied strain. Data are included in Appendix A and indicate good agreement with gradients noted for uniaxial tensile properties.

(c) Chemical Evaluation of Propellant by FTIR (Transmission Spectra of Chloroform Extracts)

Softening at the bondline is supported by chemical tests. The amount of extractable CTPB increases slightly in the propellant layer adjacent to the bondline interface (0.025-in.-deep), which indicates a slight softening at the interface. FTIR spectral data shows minimal changes in the degree of crosslinking in the bulk propellant after 18 mo aging compared to 12 mo aging. The amount of extractable CTPB is similar between the two aging intervals at distances greater than 0.2 in. from the interface. The CTPB peaks in the extracts are indicative of the amounts of short chain polymers soluble in chloroform. The 970 WN peak (trans C=C) exhibits the trend common to all CTPB peaks when normalized to initial weights (see Figure 43).

FTIR spectral data shows diffusion of additional DOP from the V-45 insulation into the propellant at 18 mo aging compared to 12 mo aging. The amount of DOP in the propellant depends on the insulation thickness and time. Since the insulation is thicker in the forward end than the aft end, the amount of DOP in the propellant is greater in the forward end than the aft end.

The relative amount of DOP in the propellant is measured by the ratio of the 1295 WN peak to the initial weight. The changes in this ratio with aging time are shown in Figure 44.

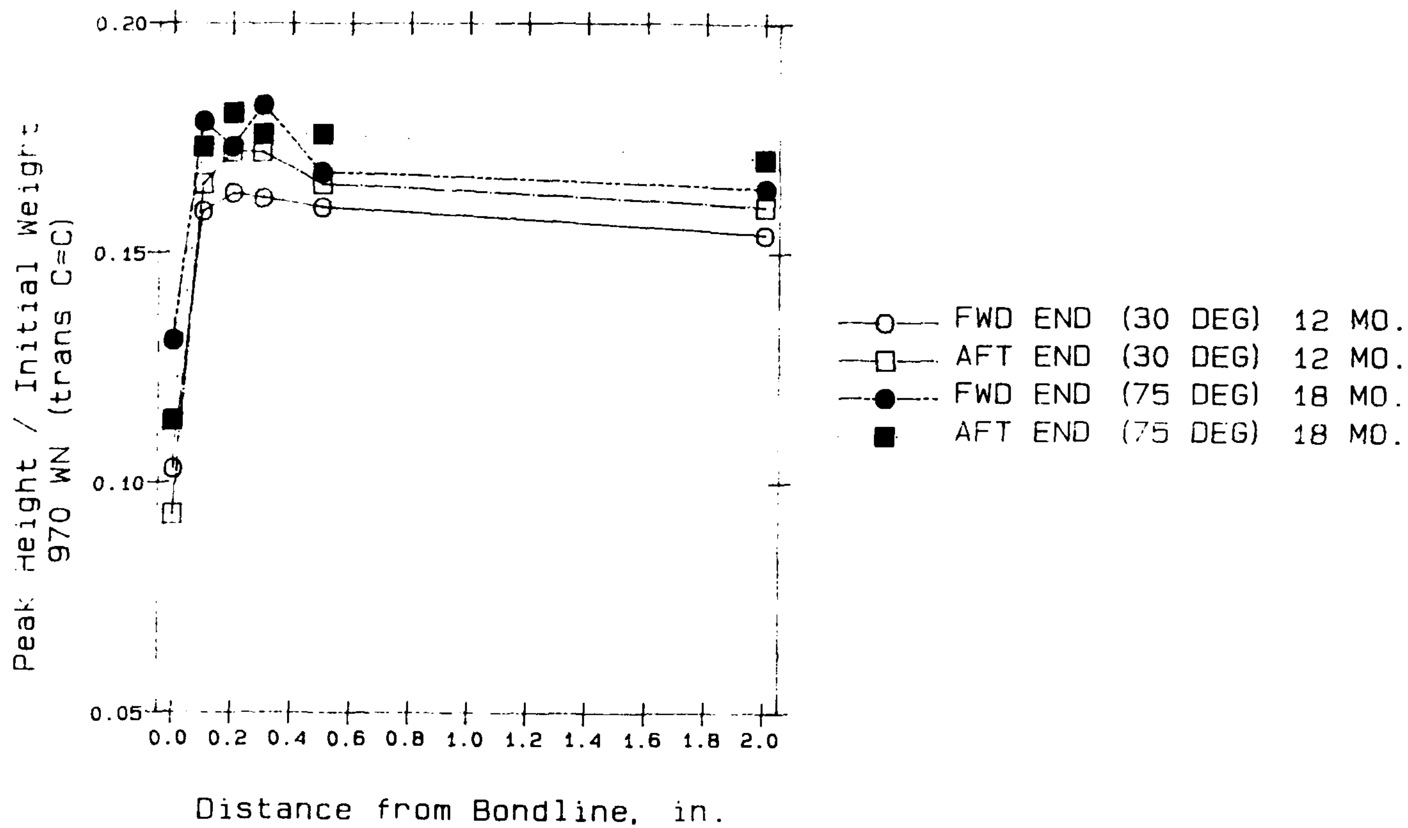


Figure 43. Amounts of Extractable CTPB Indicated by Absorbance of 970 WN Peak Normalized to Initial Weight

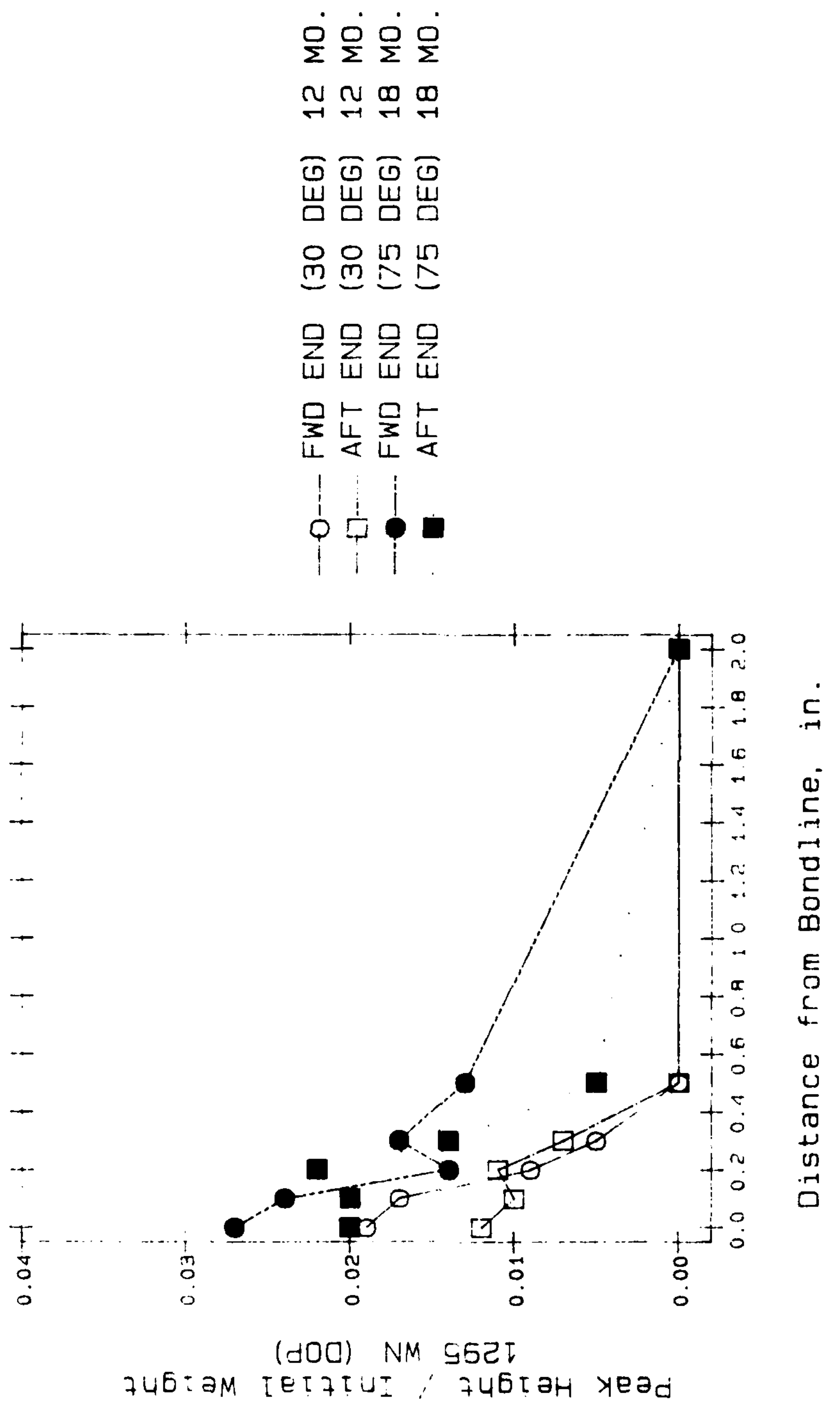


Figure 44. DOP Migration From V-45 Insulation Monitored By Height of 1295 WN Peak (Normalized to Initial Weight)

VI.C. Special Topics (Cont)

Data tables are included in Appendix A. For a full explanation of the capabilities of FTIR, see SAAS-34.

(3) Propellant-Liner-Insulation Bond

Bond tensile and bond shear strength for samples from Motor MSEX-2 were slightly improved with 6 mo additional aging. Strength of the propellant-liner-insulation bond (ANB-3066/SD-851-2/V-45) for plugs from the forward and aft end was determined using both constant rate tensile tests and high rate shear tests. Tensile tests were conducted using mini-sized specimens (1.0 x 1.0 x 0.5 in.) to reduce effects of curvature in the samples.

Previous experience, based on tests conducted on laboratory samples, indicates that an initial increase in bond tensile strength is expected due to postcure. This increase is evident in results of constant rate tests for an excised sample (aged 2.5 mo) and plugs (aged 12 and 18 mo) in comparison with comparable data from a population of 12 unaged motors, as shown below:

Source	Sample Type	Age, mo	Bond Strength, psi* Mean	Bond Strength, psi* Range	No. of Specimens
Population	Excise	0	75.4	56 to 92	24
MSEX-2	Excise	2.5	85	81 to 98	2
	Plugs	12	97	76 to 109	8
		18	109	88 to 124	4

* Based on mini-sized specimens, 77°F, 1.0 min^{-1}

Bond tensile strength in the aft chamber increased slightly, strengths in forward barrel were unchanged with aging.

VI.C. Special Topics (Cont)

Bond shear strength, measured at operational conditions (77°F, 200 in./min, 600 psig superimposed pressure), are approximately equivalent in the forward and aft areas (219 and 224 psi, respectively). Values have increased slightly during the 12- to 18-mo test interval.

On the basis of results from previous programs, no significant decrease in high rate shear stress is expected with respect to storage time (Reference 8).

The predominant mode of specimen failure continues to be either (a) within the liner, or (b) between the propellant and liner.

(4) SD-851-2 Liner

Chemical test results from gel-filler fraction show no change with age in the liner from the forward barrel; an increase with age is shown in the liner from the aft barrel. These data are consistent with results noted for bond tensile strengths in which tensile strength increased in the aft chamber. A high gel-filler fraction indicates a greater degree of crosslinking, as expected in a more strongly bonded area.

Chemical testing of SD-851-2 liner consists of swelling ratio and gel-filler fraction. Data are presented in Appendix A. The swelling ratio values obtained are highly variable, resulting from pre-stressing which occurs during removal of the thin liners (<0.03 in.) from the V-45 insulation. The pre-stressing of liners appears to have little effect on gel-filler fraction. The gel-filler fraction values reported are corrected for variations in liner thickness. Discussion of the correlation of liner thickness and gel-filler fraction is presented in Appendix A of SAAS 34.

VI.C. Special Topics (Cont)

(5) V-45 Insulation

Response properties of V-45 insulation from plugs were evaluated by stress relaxation tests conducted at 77°F with 2.0% applied strain. Relaxation modulus of material from the forward chamber decreased slightly; values for insulation from the aft area are considerably lower than expected.

Property	Age, mo	Plug Location Forward	Aft
E_{r_1}, psi*	12	1,285	1,312
	18	1,259	826

* Relaxation modulus at one minute.

Possible causes for this decrease in E_{r_1} will be evaluated when additional data become available.

Results for chemical testing are similar for insulation from the forward and aft chambers of the motor. The anomaly observed in the mechanical properties of the aft area insulation is not observed in the chemical properties.

Chemical properties reflect no change with an additional 6 mo aging, with the exception of insulation density. Density of the insulation from both motor locations increases; yet values remain within the range of data observed for insulation from a population of analog cartons, aged 12 mo at ambient (n = 11). The apparent increase in DOP concentration with additional aging is due to differences in specimen preparation from 12 to 18-mo intervals. Tests procedures were modified to account for differences in insulation thickness. Effect of differences in preparation techniques are being evaluated.

VI.C. Special Topics (Cont)

Chemical testing of V-45 insulation consists of swelling ratio, gel-filler fraction, % DOP, % moisture, density, and Shore A measurements. Data are presented in Appendix A.

4. Dissect Motor AA22050

a. Introduction

This section summarizes results of work performed to date on dissected Motor AA22050, a 1980-vintage remanufactured (weathersealed) motor. Of particular concern for a weathersealed motor are changes at the bore surface and bond areas which may result from weathersealing. Results for these areas are introduced; a complete report will be issued when analysis of data is complete.

Dissection of full-scale motors provides information concerning aging behavior of production materials from motors stored under actual environmental and structural loading conditions. Four remanufactured motors, ranging in age from 4 to 9 years, will be dissected over an 11-year period. Subsequent tests of motor remnants will provide additional information regarding motor aging as well as a direct comparison of motors from various years of manufacture.

(b) Motor Background

Motor AA22050 (ASPC R1-050) was cast 21 April 1980 from Lot Combination 75D, propellant Batches M4958, 59, and 60. The motor was core-stripped 3 May 1980 and shipped to OO-ALC in July 1980. It has been stored at Whiteman Air Force Base, Missouri (Silo 4C09, Missile 668293) for the period from 22 October 1980 to 15 October 1984. The motor was then recycled to

VI.C. Special Topics (Cont)

Hill Air Force Base for dissection and subsequent shipment to ASPC. Segments, received at ASPC in April 1985, were tested during August 1985. The samples were aged for 64 mo at time of test.

c. Scope/Status

Mechanical properties testing is complete for propellant-liner-insulation samples from the forward bore (Area A), forward and aft Y-joints (Areas C and F), and forward and aft boots. A sectioning diagram for the motor is provided in Figure 45. Chemical testing of the booted areas was excluded from the revised test plan (in error). Testing is in process.

Remnants of Motor AA22050 will be carefully wrapped to maintain effects of the weatherseal. Testing of remnants is scheduled to begin in 1988 in accordance with the current test plan.

d. Summary of Results (Preliminary)

(1) Bulk Propellant

Uniaxial tensile properties of bulk propellant were measured at various locations within the motor. Results indicate close agreement in properties among locations tested.

		Uniaxial Tensile Properties*				
Location	Area	σ_m, psi	ε_m, %	ε_b, %	E_o, psi	Shore A
Forward Bore	A	143	14	18	1,554	64
Forward Y-joint	C	141	14	18	1,528	68
Aft Y-joint	F	139	15	21	1,428	65

*Tested at 77°F, 0.74 min^{-1}, hoop orientation

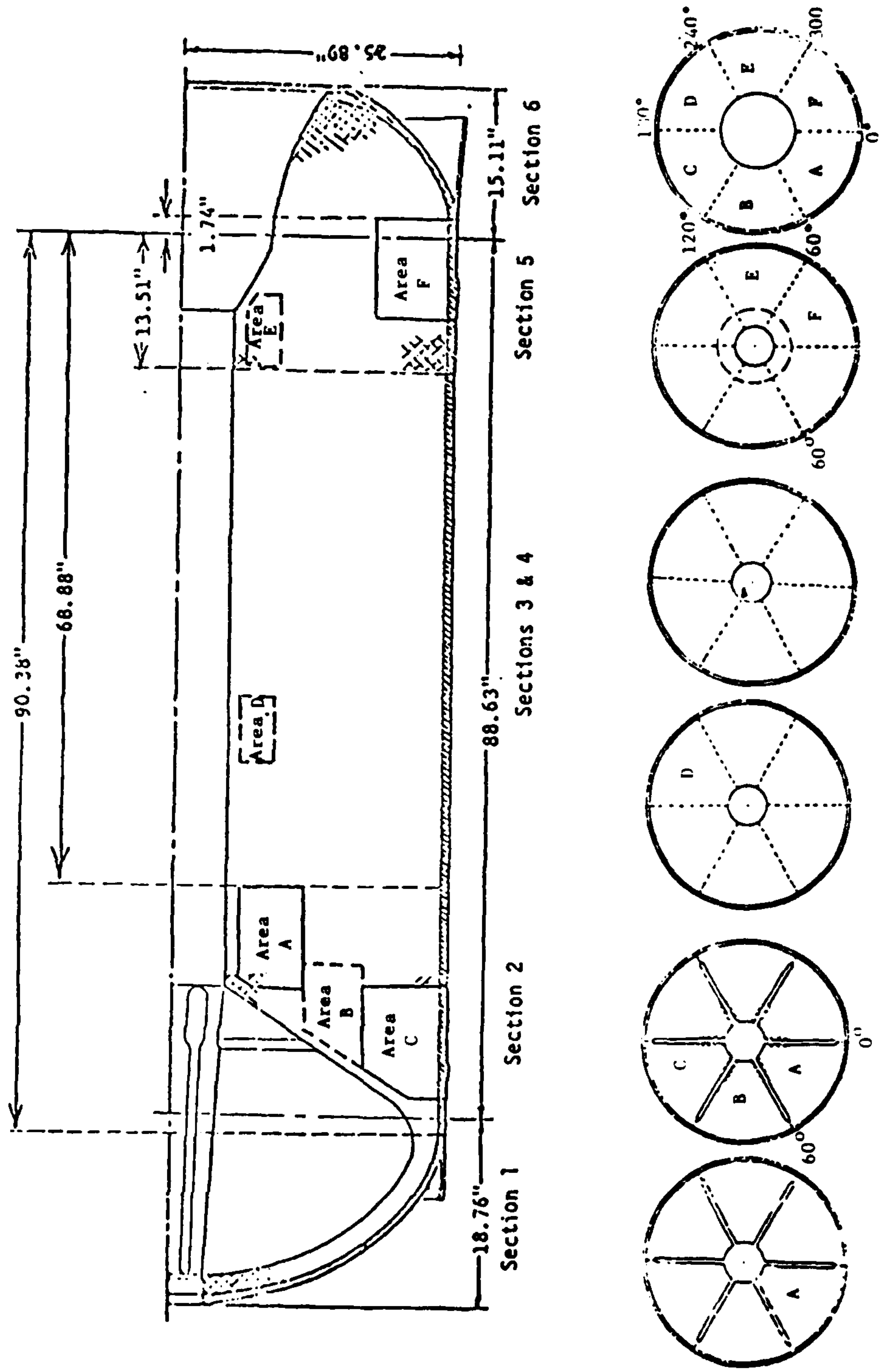


Figure 45. Sectioning and Sampling Area Diagram, Dissection Motors

VI.C. Special Topics (Cont)

Strength and modulus values are typical of bulk propellant removed from aged motors (Phillips CTPB). Strain capability is below average compared to data for comparably aged motors. Data will be evaluated with respect to initial properties at time of cast (batch qualification data) and limited data from laboratory samples cast from Lot Combination 75.

(2) Gradient from the Bore

Gradients in uniaxial tensile properties as a function of distance from the bore were evaluated at 77°F, 1.0 min^{-1} for propellant from the forward bore. Data indicate the presence of a hardened layer to 0.2 from the surface (Figure 46). Strain capability at the surface is approximately half of that at 2.0 in. from the surface.

(3) Propellant-Liner-Insulation Bond

Bond tensile strength was measured at various locations in the motor to evaluate effects of aging on bond capability. Data indicate reduced bond tensile strength in the forward and aft boot areas of the motor in comparison with the chamber area (Figure 47). Based on a comparison of data from a non-weathersealed motor of appoximately the same age (Motor AA20846, 57 mo), bond strengths in the forward boot may be improved by the presence of the weatherseal. No difference in strength is evident in the aft boot area.

An additional bond strength gradient at a different angular location will be performed to confirm test results. In addition, results of chemical tests currently in process will confirm the degree of liner degradation in the areas of reduced bond strength. Data will be evaluated with regard to processing methods for the insulation: the possible presence of moisture in the boots at time of cast could result in hydrolytic degradation of the liner and subsequent reduction in bond strength.

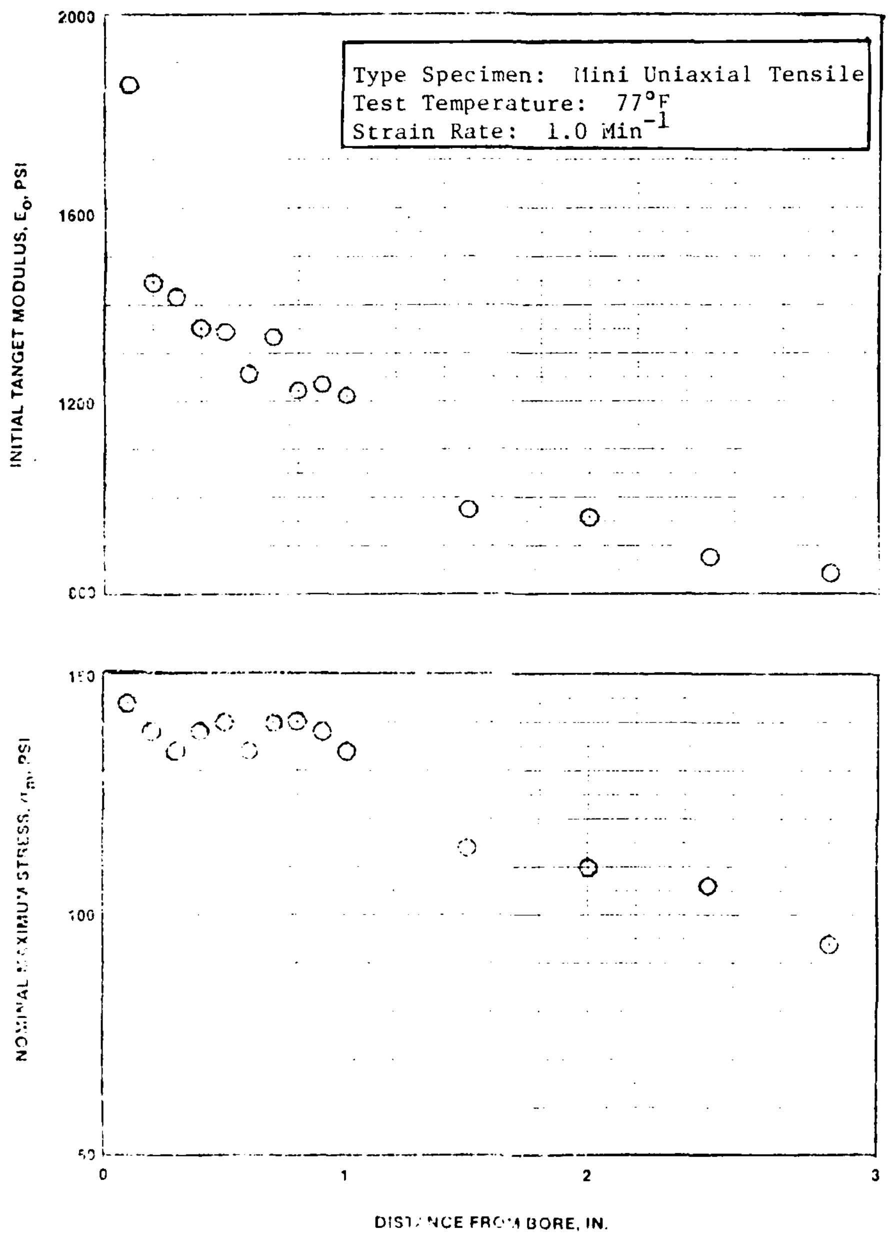


Figure 46. Effect of Distance from Bore on Uniaxial Tensile Properties of ANB-3066 Propellant Removed from Motor AA22050, Sheet 1 of 2

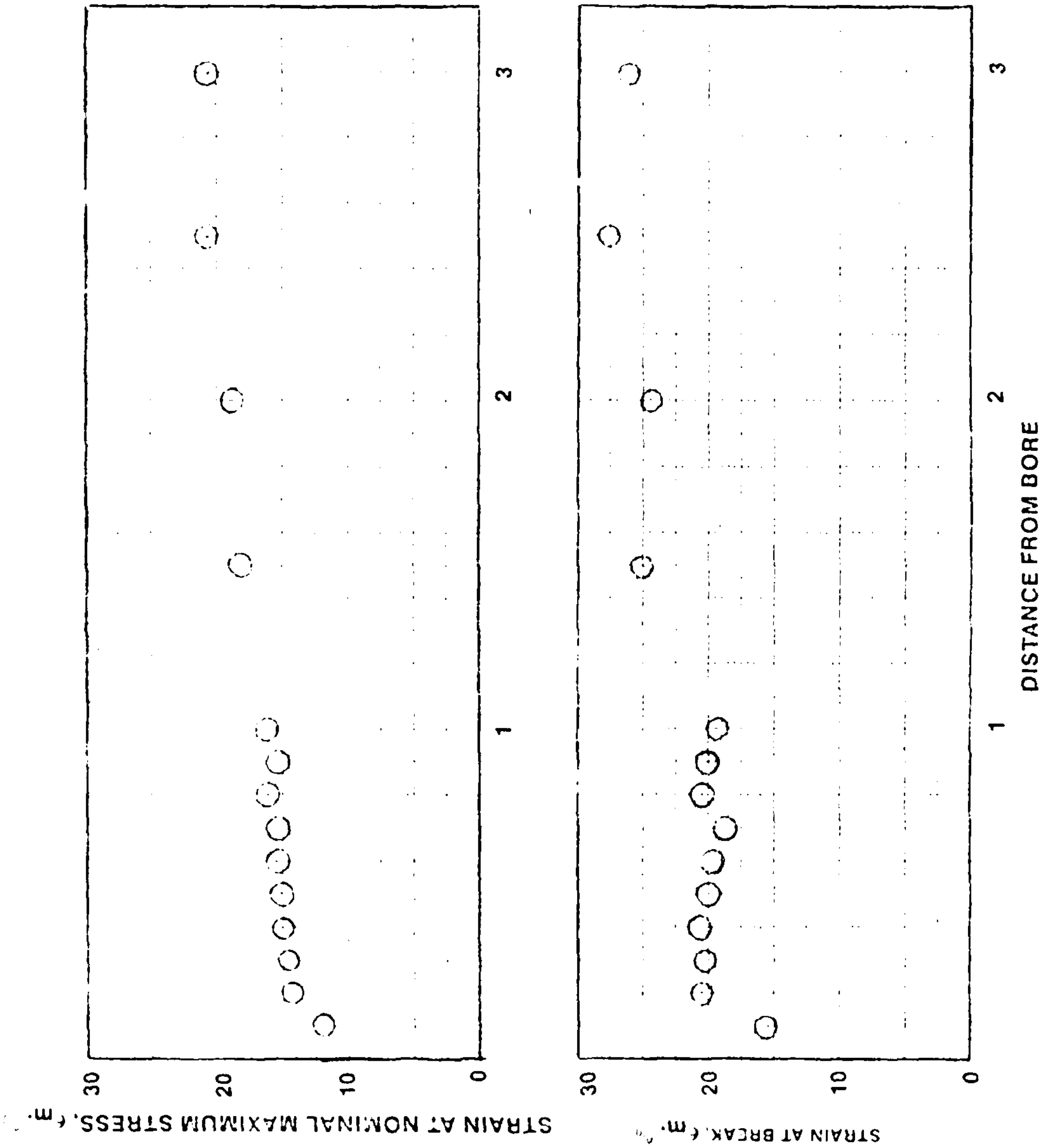


Figure 46. Effect of Distance from Bore on Uniaxial Tensile Properties of ANB 3066 Propellant Removed from Motor AA22050, Sheet 2 of 2

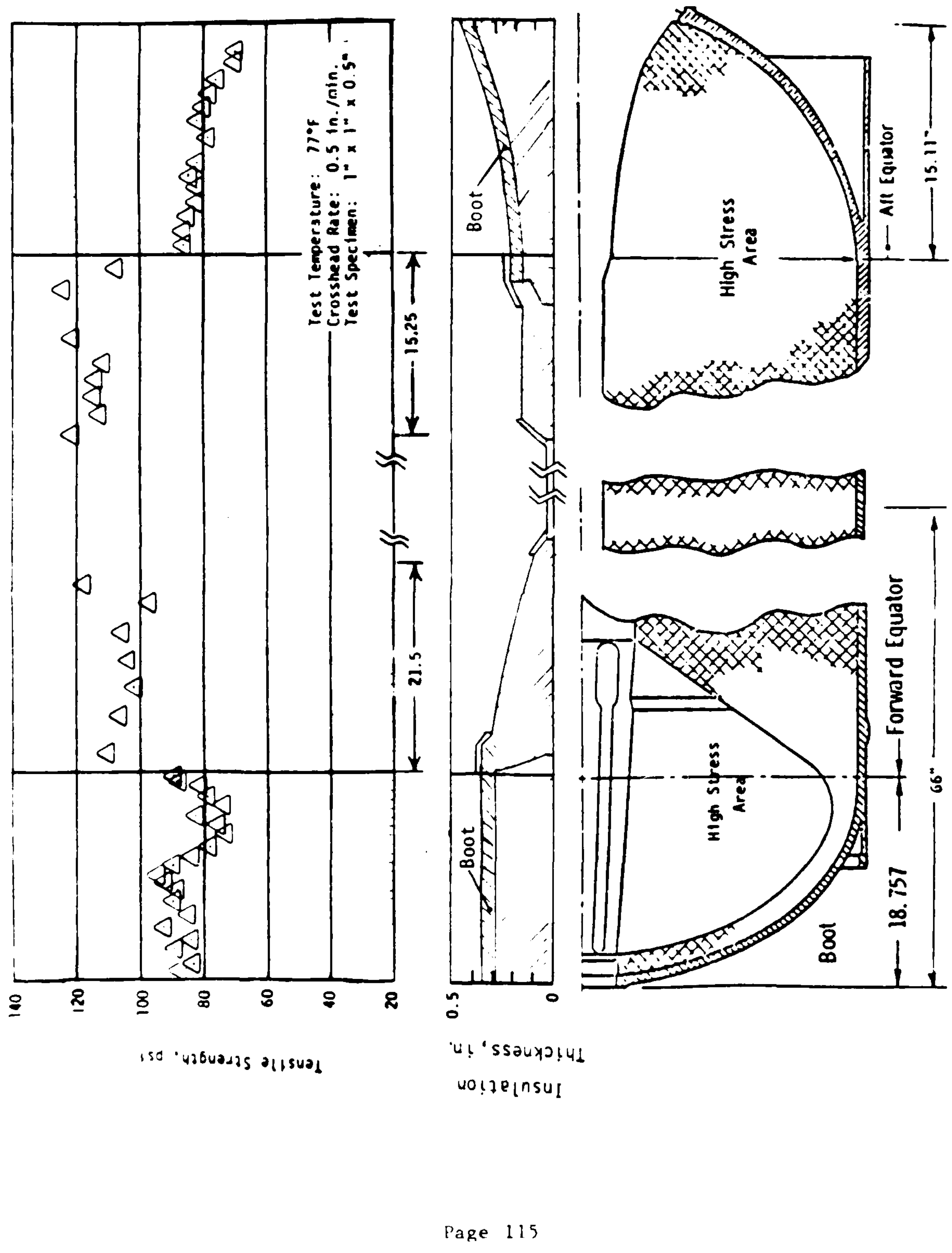


Figure 47. Effect of Sample Location on Bond Tensile Strength Motor AA22050

VI.C. Special Topics (Cont)

5. Igniter Performance Verification (VECP B-177)

a. Introduction

This section describes mechanical and chemical testing of igniter propellant performed to date as part of the Igniter Re-Use program [Value Engineering Change Proposal (VECP) B-177]. This program was initiated in 1985 to demonstrate acceptable aging characteristics of field-returned Minuteman III Stage II igniters in support of re-use in remanufactured motors (requiring a total service life of 34 years).

The igniter is displacement cast with ANB-3066 propellant bonded to an FM-47 primer-coated steel chamber.

b. Scope

Three Minuteman III Stage II igniters were dissected to assess the ability of aged ANB-3066 propellant in a sealed environment to withstand additional storage of up to 17 years (total of up to 34 years). Igniters from Lots 21 and 41 were aged 233 and 221 mo, respectively, before dissection. Although ANB-3066 propellant is well-characterized using both laboratory and motor samples,* an unaged igniter (Lot 127, aged 2 mo) was dissected to determine effect of igniter configuration on initial properties of the propellant.

Propellant evaluation included:

- Visual inspection during disassembly
- Surface examination using SEM
- Uniaxial tensile properties and hardness profiles at various locations

*Same propellant used in Stage II and Stage III motors

VI.C. Special Topics (Cont)

- Chemical tests (gel-filler fraction, swelling ratio)
- Fourier Transform Infrared Spectroscopy
- Moisture and gas concentrations of gas samples removed from the bore.

Where possible, tests were performed using specimens and procedures used in previous programs for a direct comparison with the database. The test plan is provided in Figure 48. Description of specimen locations is shown in Figure 49.

c. Summary of Test Results

Results of mechanical and chemical tests completed to date are summarized below. A final report will be issued following completion of initial testing.

Visual Inspection - No age-induced anomalies were identified for dissected igniters. Igniters were inspected for cracks, waves or slump on the propellant surface, evidence of bond separation or degradation between the igniter chamber and propellant, and flaws in metal components.

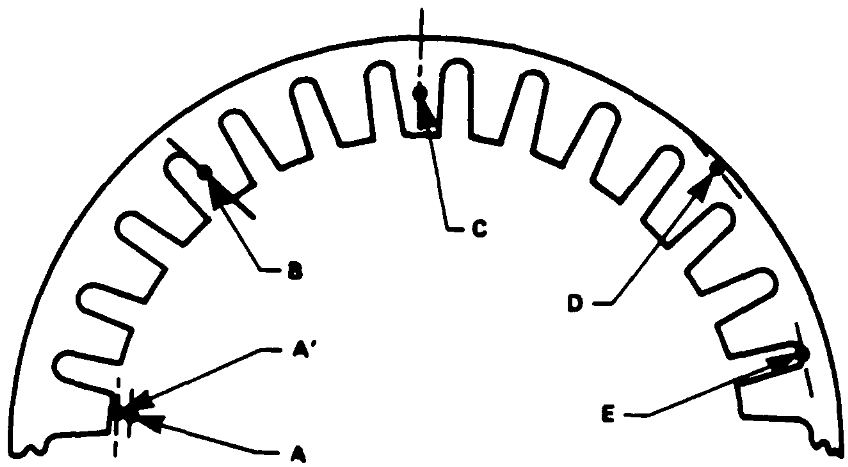
Scanning Electron Microscope - Propellant surfaces were free of recrystallized ammonium perchlorate (AP recrystallization is an indicator of moisture). This information is also used to predict ignition delay.

Uniaxial Tensile Properties - Results for aged igniters indicate little change in properties with up to 18 years real-time aging (Figure 50). Initial tangent modulus for unaged propellant ranges from 300 to 600 psi (target is 450 psi). Modulus ranges from 601 to 687 for Igniter 2026509 (Lot 21, aged 233 mo) and from 485 to 703 for igniter 2027006 (Lot 41, aged 221 mo).

Material	Type Test	Test Temperature, °F	Crosshead Rate, in./min	Remarks
Propellant	Mini Uniaxial Tensile*	77	1.0	Measured at fin surface, slot surface, bulk of web as described in Figure 5
	Shore A Hardness (15 sec)*	77		Measured at locations described in Figure 5
	Swelling Ratio*			Measured at fin surface, slot surface, bulk of web (Figure 5). Differences in test procedures (single solvent versus dual solvent) will require duplicate testing to correlate with 10 year data base
	Gel Filler Fraction*			
	FTIR			
	Gas Chromatograph Analysis*			Two samples will be required to determine (a) gas concentrations and (b) percent moisture
	Microscopic Examination*			Check for AP crystallization due to presence of moisture
Insulation/ Case Bond	Lap Shear*	77	To be supplied	Limited assets available from previous aging program (stored to approximately 20 years at 80°F)

* Limited data from 10-year real-time storage available for correlation with test results

Figure 48. Recommended Tests for Evaluation of Aged Minuteman Stage II Igniters



LOCATION

A - BORE

B - FIN

C - BULK FIN

D - BULK

E - SLOT

Figure 49. Location of Testing to be Conducted on Minuteman Stage II Igniters

Serial No.		2026509					2027006					7061355				
Igniter Lot		21					41					127				
Age, months		233					221					[illegible]2				
CTPB Vendor							Phillips					Phillips				
Cast Date							1-12-67					3-11-85				
Specimen Location		σ_m, psi	ϵ_m, %	ϵ_b, %	E_o, psi	Shore A	σ_m, psi	ϵ_m, %	ϵ_b, %	E_o, psi	Shore A	σ_m, psi	ϵ_m, %	ϵ_b, %	E_o, psi	Shore A
A Bore						58					58					67
B Fin		86	23.6	30.3	657	52	78	24.4	41.0	544	52	133	19.2	27.0	1,147	63
		89	21.0	26.2	687	52	79	28.8	41.0	515	56	130	15.9	22.2	1,234	62
		86	24.0	31.8	630	52	81	29.2	41.8	614	52	133	18.8	24.7	1,133	64
		88	22.5	28.8	644	51	73	24.7	42.9	630	54	124	19.9	24.7	943	65
	x	87	22.7	29.2	654	52	77	26.7	41.6	575	54	130	18.4	24.6	1,114	64
C Bulk Fin						54					58					64
D Bulk		90	22.2	26.6	657	60	78	24.4	38.8	601	59	136	16.2	20.7	1,161	68
		86	23.6	27.3	657	52	78	24.7	32.1	558	62	136	17.0	23.6	1,161	63
							86	29.2	41.4	703	57	136	15.9	21.8	1,247	68
												138	17.0	22.9	1,234	69
	x	88	22.9	26.9	657	56	80	26.1	37.4	620	59	136	16.5	22.2	1,200	67
E Slot		90	27.3	31.4	644	47	79	28.4	41.4	501	48	121	18.8	24.4	1,030	55
		81	21.4	22.2	601	52	77	29.2	46.6	571	45	127	16.6	19.2	1,204	53
		82	18.8	21.0	614	47	76	28.4	41.0	485	46	114	16.6	19.9	1,000	54
							78	28.8	43.6	528	47	110	15.5	17.0	986	50
	x	84	22.5	24.9	620	48	77	28.7	43.1	521	46	118	16.8	20.1	1,055	53
Qualification Data Batch 88D-3066 M5007 (JANNAF Specimens, Strain Rate = 0.74 min^{-1}												91	33	54	451	

Type Specimen: Mini Uniaxial Tensile
Test Temperature: 77°F
Strain Rate: 1.0 min^{-1}

Figure 50. Summary of Mechanical Properties for ANB-3066 Propellant from Aged Stage II Igniters

VI.C. Special Topics (Cont)

Lot 41 has been identified as a propellant batch formulated with Phillips CTPB; CTPB vendor for Lot 21 is unknown. Properties for both aged igniters appear typical of aged GTR propellant: surface hardening associated with aged Phillips propellants in motors is not apparent in Igniter 2027006 (Lot 41). This may be related to sealing the igniter following assembly.

In general, propellant in the bulk of the web is slightly harder than that measured in the fin. Propellant in the slot surface tends to be softest (lowest strength and modulus, highest strain capability).

The unaged igniter (SN 7061355, Lot 127) was cast with propellant formulated with Phillips CTPB. Data indicate significant propellant hardening following 2 mo. aging. Properties of the propellant batch cast into the igniter (Lot Combo 88D, Batch M5007) were acceptable at time of cast, based on qualification data from laboratory samples. This problem will be investigated independently of the igniter re-use effort. Data for this igniter will not be considered part of the aging database.

Shore A Hardness - Measurements are consistent with results of uniaxial tensile tests (Figure 50).

Chemical Tests - Results from chemical tests are in agreement with mechanical test results (Figure 51).

Gel-filler fraction values are higher for the unaged igniter than the aged igniters. A higher value is indicative of harder propellant. Gel-filler fraction also reflects the variation in propellant hardness seen with respect to location; values are slightly higher for propellant from the bulk of the web compared to the values from the fin and slot surface in the three igniters.

	Igniter 2026509		Igniter 2027006		Igniter 7061355	
Location	Gel-Filler Fraction	970 WN*	Gel-Filler Fraction	970 WN*	Gel-Filler Fraction	970 WN*
Bulk	0.927	0.240	0.992	0.260	0.944	0.158
Fin	0.924	0.256	0.919	0.271	0.939	0.174
Slot	0.924	0.251	0.918	0.282	0.932	0.192

* Peak Height of 970 WN Peak (normalized to initial weight) is Indicative of the Amount of Extractable CTPB

Figure 51. Chemical Properties of Propellant From Igniters

VI.C. Special Topics (Cont)

FTIR analysis of the propellant extracts concurs with the previous results: the differences in the amount of extractable CTPB reflects the differences in the hardness of the propellant (Figure 51).

Gas Chromatography - Moisture and gas concentrations of samples removed from the bore are typical of ambient air.

Comparison with Previous Data

Properties for both aged igniters are in close agreement with data for an aged GTR igniter dissected in 1980 (approximately 17 years old at time of dissection). Shore A measurements are consistent with values for propellant removed from eight igniters tested prior to 1973. Data are compared with results of previous testing in Figure 52.

TEST DATE	AGE AT TEST, MOS	IGNITER NO.	GRAIN CONFIGURATION	PROPELLANT BATCH	CTPB VENDOR	SHORE A HARDNESS			
						BORE	FIN	BULK	BULK FIN
5-67		2026384				63	63	-	63
8-68		64-5-CP6-08	NET CAST, TRIMMED	17 DU81(MS)	GT&R	56	58	54	54
1-69	36	2026459-7				70	70	72	72
7-70		64-5-CP6-20	NET CAST, TRIMMED	17 DU81(MX)	GT&R	56	54	52	52
12-70		2026389				57	55	56	55
6-72		64-5-AP6-05	NET CAST, TRIMMED	17 DU77(M2)	PHILLIPS	58	56	53	53
1-73		2026464				72	67	69	63
12-80		2026392	NET CAST, TRIMMED		GT&R	69	63	62	61
12-80		63-11-AP6-12	NET CAST	17 DU41(MI)	PHILLIPS	60	48	46	47
8-85	233	2026509				58	52	56	54
8-85	221	2027006		18 DM151	PHILLIPS	58	58	59	58
8-85	2.5	7061355		88D M5007	PHILLIPS	67	64	67	64

Figure 52. Summary of Test Results Motors AA21049 vs AA21321

VII. TECHNICAL DISCUSSION OF COMPONENTS

A. MOTOR POSTFIRE INSPECTION (TP-A52)

The first static firing of an operational remanufactured motor is scheduled for FY 1986. No motors were fired during this report period.

B. IGNITER FIRINGS

1. VECP Igniter Firings (VECP B-177)*

To enable reuse of igniters on remanufactured motors, VECP B-177 was implemented to verify a motor igniter service life of 34 years. Nineteen igniters from motors returned to ASPC for remanufacture were fired to support VECP B-177 in August and September 1985. All firing parameters were within respective lot acceptance ranges except for igniter delay. No observable aging trends were noted.

Eight of the nineteen igniters fired had igniter delays which were high compared to respective lot acceptance delays. Ten of the nineteen had delays outside lot acceptance 3-sigma limits. Figure 53 compares VECP igniter delays to lot acceptance limits.

*This report is preliminary. A final presentation of analysis will be reported in SAAS 36. Propellant evaluation of VECP igniters is presented in Section VI of this report.

VII.B. Igniter Firings (Cont)

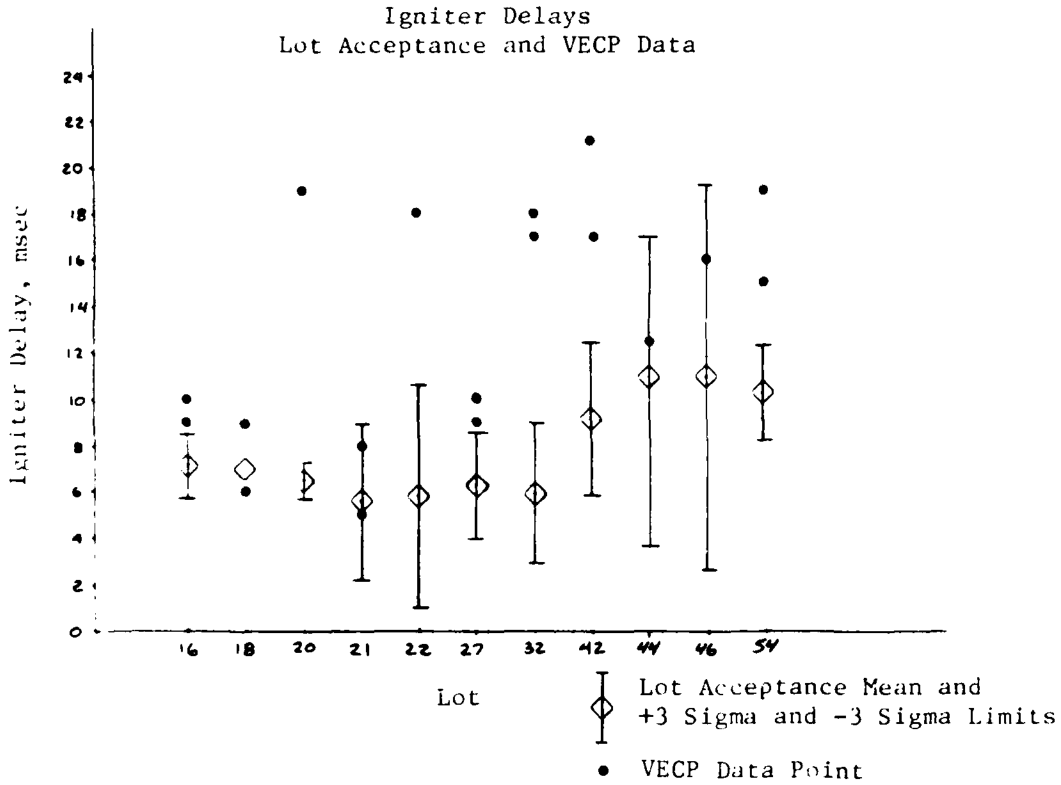


Figure 53. Igniter Delays Lot Acceptance and VECP Data

The high igniter delays were a result of either aging, test set-up, igniter contamination, normal igniter variability, or some combination of these.

Figure 54 shows ignition delay values from PQA and OP motor firings.

VII.B. Igniter Firings (Cont)

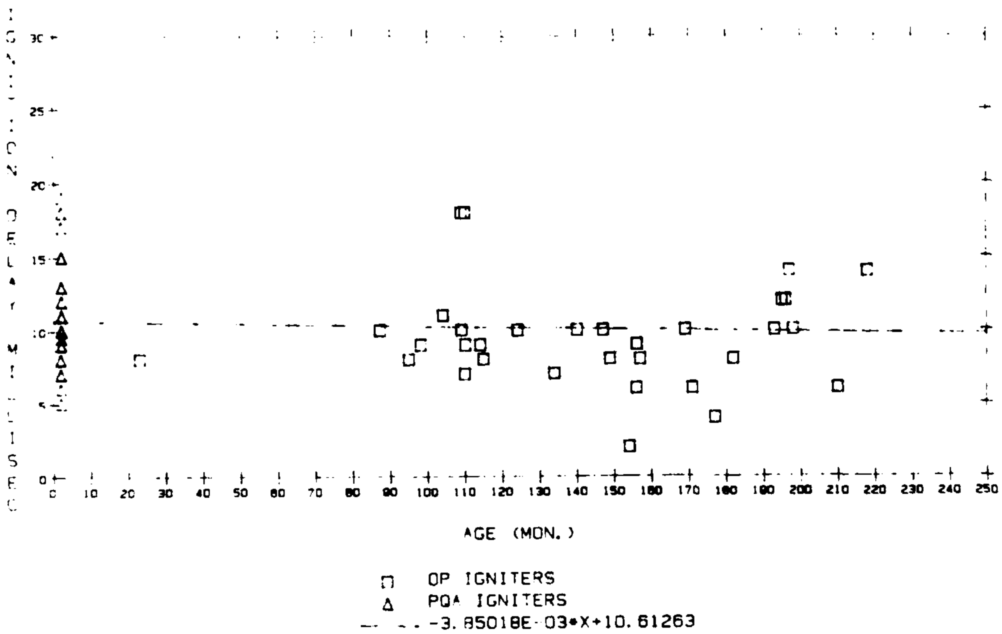


Figure 54. Ignition Delay vs Age - Igniters Fired on PQA and OP Motors

PQA motor igniters are essentially unaged while OP motors offer a wide age range of igniter data. This plot does not address igniter lot-to-lot variability but shows that igniter delay values from PQA and OP motor igniters are not significantly different. Also, scatter of unaged PQA delays and of aged OP delays is similar. This suggests that the effect of igniter age on igniter delay is negligible. Figure 54 shows the result of adding VECP data to Figure 55.

VII.B. Igniter Firings (Cont)

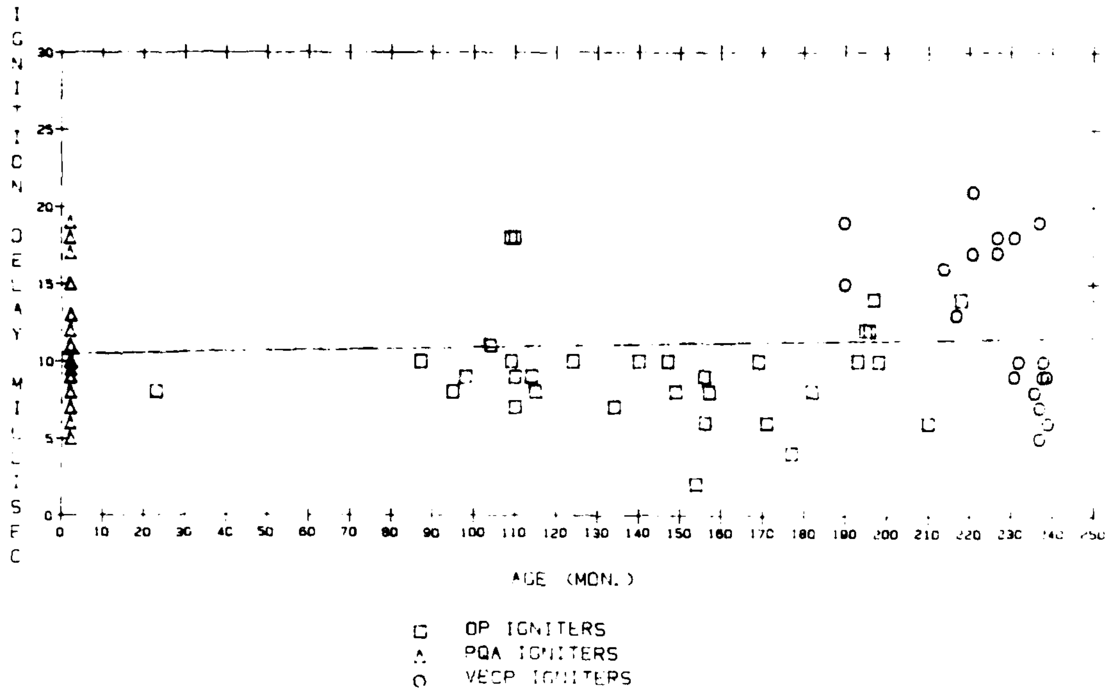


Figure 55. Ignition Delay vs. Age - Igniters Fired on PQA and OP Motors, and for VECP

Ten of the nineteen VECP igniters are part of the PQA-OP population while the other nine are above this population. Since all VECP igniters are approximately the same age, these two different VECP delay populations infer that the high delays were most likely not a consequence of igniter age.

Figure 56 shows lot acceptance igniter delays versus lot.

VII.B. Igniter Firings (Cont)

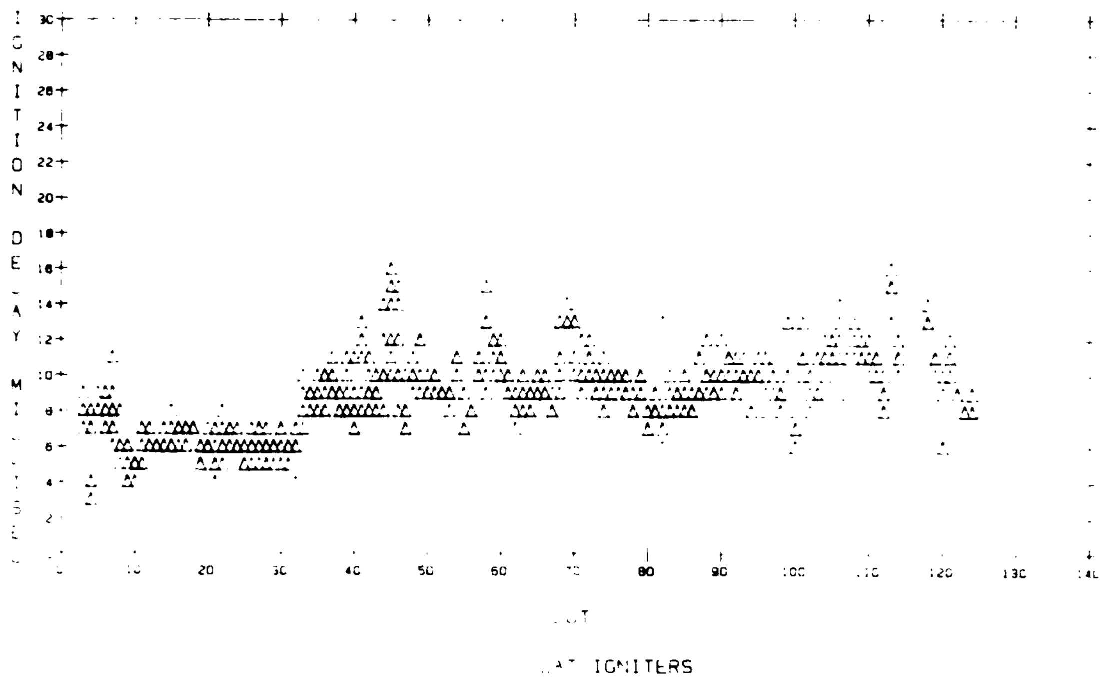


Figure 56. Ignition Delay vs Lot LAT Igniters

Note that delays of pre Lot 30 lot acceptance igniters are significantly lower than delays of post Lot 30. This suggests that igniters from Lot 30 and greater are slower to initiate and should be analyzed seperately from pre Lot 30 igniters. Figure 56 also shows high variability between lots. Because of high lot-to-lot variability, data was normalized by subtracting average lot acceptance igniter delay times from delay of each test. This was done for each test type (PQA, OP, VECP). PQA igniters tend to have delays 1.8 msec greater than lot acceptance firings. OP igniters tend to have delays 2.1 msec greater than lot acceptance firings. Pre Lot 30 VECP igniters have delays 3.6 msec greater than lot acceptance firings, and post Lot 30 VECP igniters have delays 8.1 msec greater than lot acceptance values. As a result, it is difficult to compare igniter delays from field motors directly to lot acceptance delays.

VII.B. Igniter Firings (Cont)

The result of normalizing on VECP delays is shown in Figure 57.

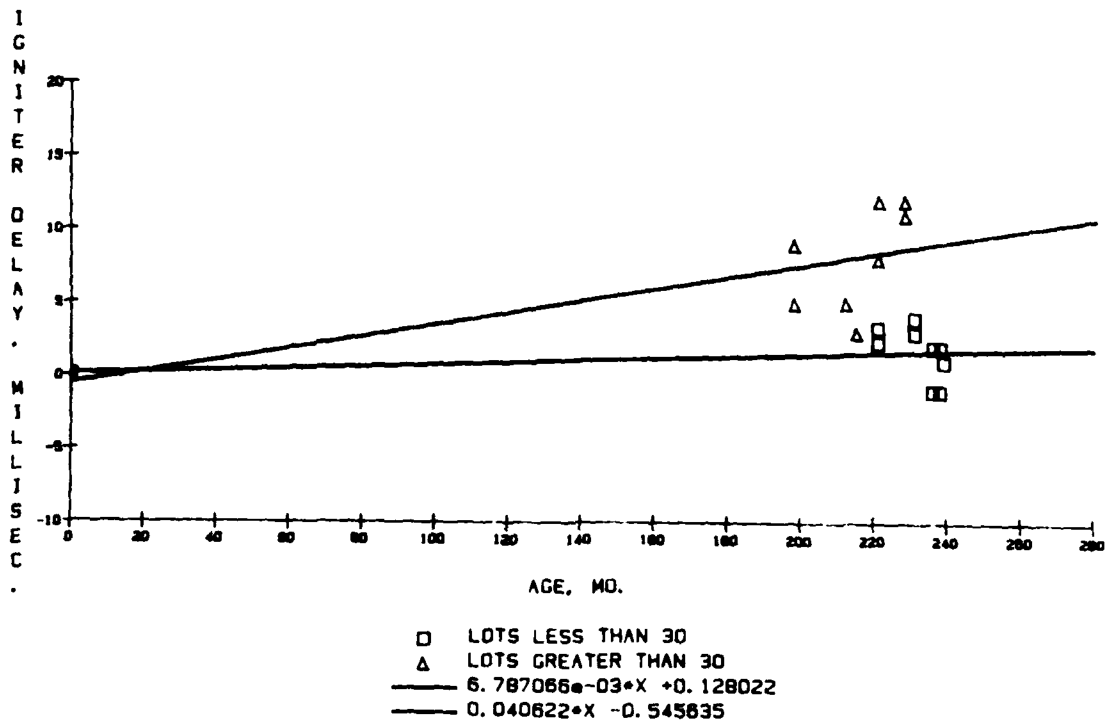


Figure 57. VECP Igniter Delay

The difference between delays of VECP igniters from pre and post Lot 30 is clearly shown. As in lot acceptance igniters, igniters from lots greater than 30 were more difficult to initiate. This appears to have been magnified in the VECP igniters. Factors which could have contributed to this shift are identified as igniter firing test set-up and/or igniter contamination. The more probable cause of slow initiation is found in test set-up. The following table shows differences between VECP testing and all other previous igniter testing.

VII.B. Igniter Firings (Cont)

	SQUIB Type	Firing Fixture Configuration
VECP Firings	One Holex 5600	Firing Adapter (Figure 58)
All Previous firings	Two ES-003	KR80000 or firing Train test fixture (FTTF) (Figure 59)

The Holex 5600 squib is known to have a higher output than the ES-003 squib, but the amount of difference is unknown. Note that only one squib was used for VECP firings. The age and history of the Holex 5600 squibs used for the VECP are also unknown. Figure 58 shows the firing adapters used to fire VECP igniters. Figure 59 shows the squib arrangement used in both KR80000 safe and arm and FTTFs.

When Figures 58 and 59 are compared, flame path is significantly longer for the VECP firing adapter than the actual field igniter squib arrangement. The firing adapters were used for the VECP firings to conserve KR80000 and FTTF squib assets.

Igniter contamination is also a possible cause of igniter delay since the igniters tested were stored unsealed* (except Lot 16). This possiblity is unlikely because only lots greater than 30 tended to have high delays and all igniters were unsealed. Igniters fired from Lot 16 were from the aging and surveillance inventory and were sealed with firing train test fixtures that were installed before aging.

* Unsealed igniters had no environmental sealing device installed on the igniter when its safe and arm device was removed upon motor return to ASPC.

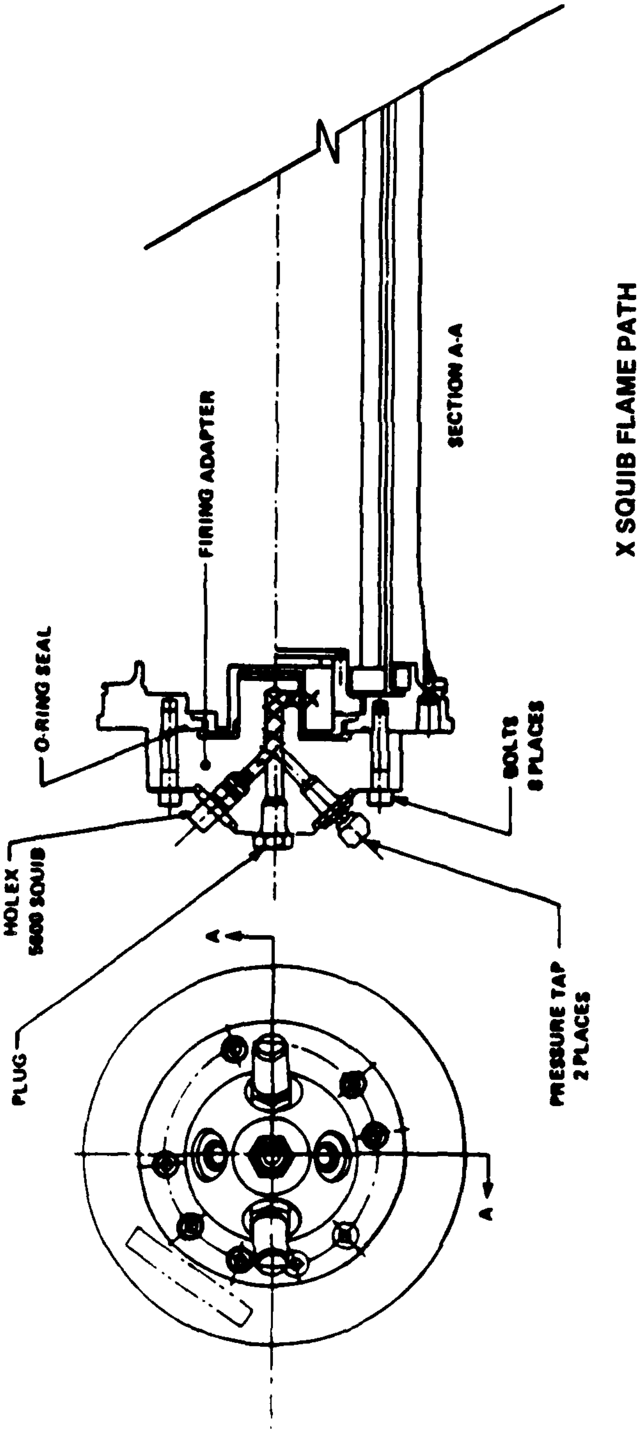


Figure 58. Firing Adapters Used to Fire VECP Igniters

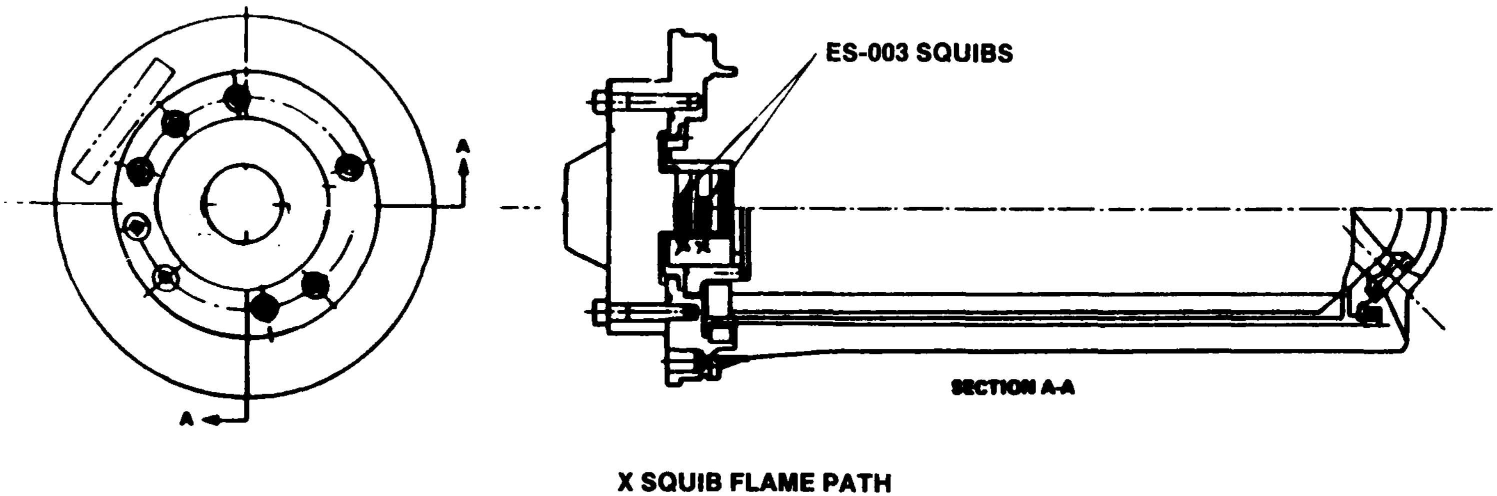


Figure 59. Squib Arrangement Used in Both KR80000 Safe and Arm FTTFs

VII.B. Igniter Firings (Cont)

To verify the cause of high VECP delay times, six more igniters are scheduled for firing. The firing plan is shown below.

Firing Number	Igniter Lot	Storage Environment	Squib Configuration	Test Fixture Configuration
1	54	Unsealed	Two HOLEX 5600	Original Fixture
2	54	Unsealed	Two HOLEX 5600	Original Fixture
3	54	Unsealed	Two ES-003	Modified Fixture
4	54	Unsealed	Two ES-003	Modified Fixture
5	54	Sealed	Two HOLEX 5600	Original Fixture
6	54	Sealed	Two HOLEX 5600	Original Fixture

Lot 54 igniters were chosen since both Lot 54 igniters previously fired for the VECP had high igniter delay times. Lot 54 was also chosen since sealed and unsealed igniters are available from this lot. Igniters from a single lot were chosen to eliminate the possiblity of lot-to-lot variability.

Four igniters will be tested with the same test fixture used on the original 19 VECP igniters except two HOLEX 5600 squibs will be used instead of one. Two of the four will be sealed igniters and two will be unsealed. Two additional igniters will be tested with a modified test fixture. The modified fixture will duplicate safe and arm and FTTF configuration, and will use two ES-003 squibs.

2. Aging and Surveillance Igniter Firings (TP-A53)

Two aging and surveillance igniters were scheduled for test this report period, but testing was delayed until complete evaluation of VECP B-177 firing data could be done. These two igniters will be fired during the next report period, and results will be reported in SAAS-36.

VII Technical Discussion of Components (Cont)

C. NOZZLE (TP-A54)

Nozzle SN 2168064 was visually inspected and pressure tested February, 1985. The SN 2168064 nozzle was the first to form a new aging database for nozzles returning to the field after motor remanufacture. The new database will include proof pressure, impact pressure, and leak testing. Each of these is a pass/fail criteria, so testing will give qualitative results only.

D. TVC AND RC GAS GENERATORS

Four TVC and three RC gas Generators were fired since the last report period. One of the four TVC and one of the three RC generators were fired for lot requalification. No anomalies were found during prefire X-ray, and firing results were within specification for all seven generators. A firing result summary is shown below.

GG TYPE	SERIAL NO	BLEND	GG AGE MO	AGING TEMP F	GG TEST TYPE	VIBRATION	IGNITION DELAY SEC	IGNITION TIME SEC	BURN DURATION SEC	MEOP PSIA	TIME TO MEOP SEC	COMMENTS
BAA	0001039.	0373.	236.00	080.00	AGING	NONE	0.0314	0.1365	097.96	2054.00	0.2795	IN SPEC
BAA	0001075.	0374.	235.00	080.00	AGING	NONE	0.0500	0.1523	092.00	2243.00	0.2940	IN SPEC
RAA	0003068.	0413.	217.00	080.00	AGING	NONE	0.0250	0.1270	990.34	2198.00	0.2940	LOT REQUAL
CAA	0001084.	0368.	236.00	080.00	AGING	NONE	0.0088	0.1500	077.34	0769.90	0.1560	IN SPEC
CAA	0001102.	0368.	236.00	080.00	AGING	PFIRE	0.0069	0.0769	078.67	0856.00	0.1530	IN SPEC
CAA	0001079.	0368.	236.50	080.00	AGING	NONE	0.0078	0.1934	077.75	0841.70	0.1635	IN SPEC
TAA	0003042.	0408.	219.00	080.00	AGING	NONE	0.0102	0.1161	078.01	1074.00	0.0000	LOT REQUAL

A list of generator firing results of the five blends tested this report period is shown in Appendix C, Pages 1 and 2.

VII.D. TVC and RC Gas Generators (Cont)

1. Generator Firings

Ballistic performance was normal for all gas generators fired except for TVC generator TAA 3042 which was fired for blend 408 requalification. Its MEOP is outside the upper 3-sigma limit of original lot acceptance data. The high MEOP resulted from a pressure spike at ignition but the MEOP was within specification. The cause of the spike could not be determined. Since MEOP was only 14 psi outside the 3-sigma limit and all other parameters were within limits, TAA 3042 was considered successful for Blend 408 requalification. Ballistics of TAA 3042 are shown below.

	Ignition Delay, sec	Ignition Time, sec	Burn Duration, sec	MEOP, psia
Specification Limit (SPC 71079)	0.150 Max	0.500 Max	74.8 Min	1200 Max
TAA 3042	0.0102	0.116	78.0	1074
Upper LAT 3-Sigma Limit	0.0275	0.159	76.7	1060

Postfire dissection of generator CAA 1102 showed the generator in normal postfire condition. Insulation was intact, and the igniter and pressure port appeared satisfactory.

2. Analysis

Data from the seven firings during this report period were added to the generator aging database and analyzed. Linear regression analysis of generators by blend is summarized in the following table.

VII.D. TVC and RC Gas Generators (Cont)

RC Blend 373	Ignition Delay	Ignition Time	Duration	MEOP
Regression Significant	Yes	Yes	No	No
Regression Equation	1.04e-4*X +0.03	1.69e-4*X +0.02	-	-
Correlation Rsq.	35%	14%	-	-
Extrapolation to 34 Years	0.07	0.192	-	-
RC Blend 374				
Regression Significant	Yes	Yes	No	Yes
Regression Equation	1.65e-4*X +0.02	1.66e-4*X +0.13	- -	0.44*X +2022.9
Correlation Rsq.	52%	44%	-	20%
Extrapolation to 34 Years	0.09	0.20	-	2203
TVC Blend 368				
Regression Significant	No	No	No	No

Regression equations are significant for ignition delay and ignition time of RC Blends 373 and 374, and for MEOP of RC Blend 374. In cases where the regression is significant, correlation is marginal. In all cases, regression slope is small enough not to endanger 34-year service life. Plots and regression analysis are presented in Appendix C, Figures 3 through 14.

VII.D. TVC and RC Gas Generators (Cont)

Linear Regression analysis was not done for TAA 3042 or RAA 3068 since data from 1985 are the only aging data points available from these blends.

3. Random Vibration (CAA 1102)

Random vibration of CAA 1102 was done 6 May 1985. The generator was subjected to a sine sweep survey of 20 to 300 Hertz with an input level of +1 g. Sweep rate was one octave per minute. Next, the generator was subjected to the following input for random vibrations:

Input level, gm Overall	Duration, sec
2.70 (-12db)	25
3.82 (-9db)	12
5.29 (-6db)	12
7.56 (-3db)	42
10.62 (0db)	120

Post vibration inspection and X-ray indicate no change in the condition of the generator. Results are included in Appendix C, Figures 15 through 21: CAA 1102 was fired successfully on 31 May 1985.

E. LITVC PERMEATION (TP-A59)

Bladder permeation testing of toroidal tank assemblies T-159 and T-210 began in April 1985. Freon permeation through the bladders is slightly slower than in previous tests, but trends are similar. Both tank T-159 and T-210 were rebuilt with Uniroyal bladders with DIAK-2 curative.* Tank T-159 contains 80% Montedison Freon and 20% distilled Freon. Tank T-210 contains 100% distilled Freon. Figure 60 shows 1985 results along with 1981 through 1983 results.

*Previous tanks were fitted with Arrowhead bladders which used DIAK 3 curative

VII.E. LITVC Permeation (TP-A59) (Cont)

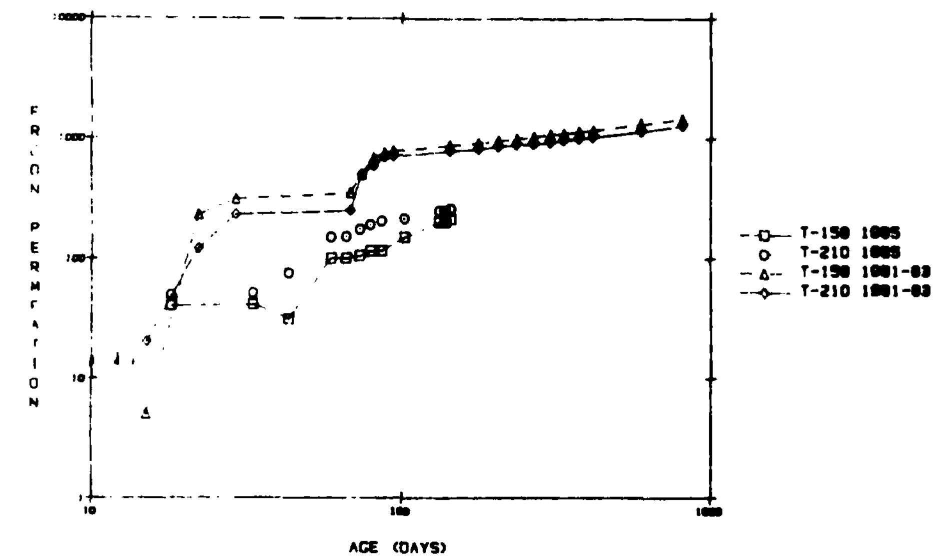


Figure 60. Bladder Permeation vs Age

Leak testing of contingency tanks T-200, T-213, and T-215 was done 7 May 1985. All three tanks had Freon leakage at the flexatallic gaskets and at the fill/drain port. Tank weighing shows that the rate of Freon loss is low enough for leakage to be considered harmless to system performance. Figure 61 shows a plot of tank weight versus age for tanks T-200, T-213, and T-215.

VII.E. LITVC Permeation (TP-A59) (Cont)

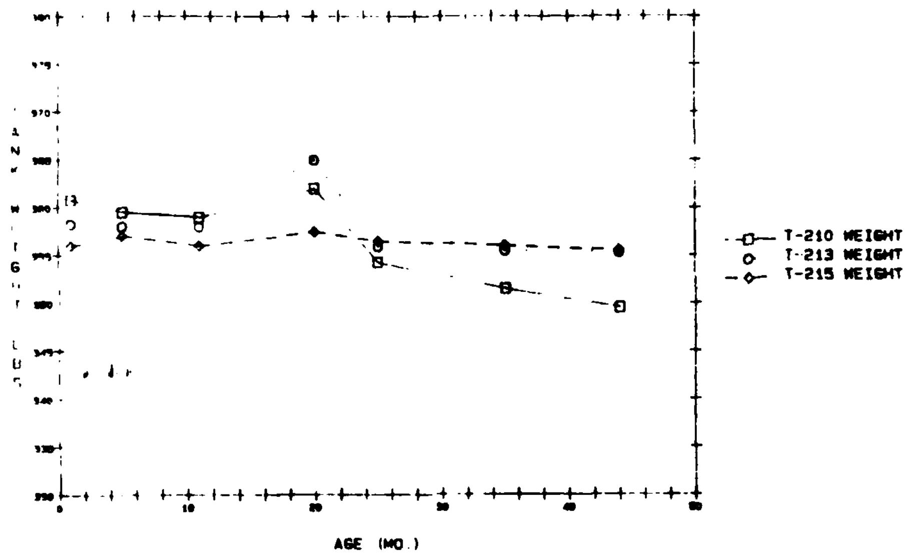


Figure 61. Contingency Tank Freon Leakage vs Time

F. TVC TANK AND COMPONENTS (TP-A59)

The results of 1985 cold flow gas explusion testing showed that the aging trend of burst diaphragms burst pressure is not statistically significant. LITVC system AAB-0535 was tested 14 May 1985, and LITVC system AAB-0469 was tested 10 June 1985. System AAB-0535 contained a 228-mo-old U.S. Rubber bladder and system AAB-0469 contained a 230-mo-old Arrowhead bladder.

The pressure/time curves recorded for both systems show noise in the test system. Because of this noise, system AAB-0469 had two burst discs which appeared to be out of specification. Both systems had high burst pressure variability. Burst pressures were subject to the pressure trace showing

VII.F. TVC Tank and Components (TP-A59) (Cont)

a peak, valley, or something in between, at the time of disc failure. The superimposed pressure transient has greater significance than the actual burst pressure trace. Figure 62 shows the original trace and first and second level smoothed pressure traces.

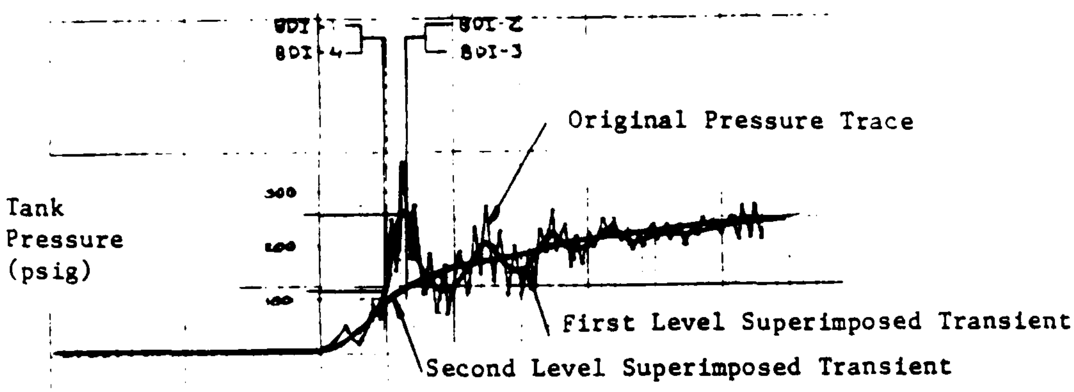
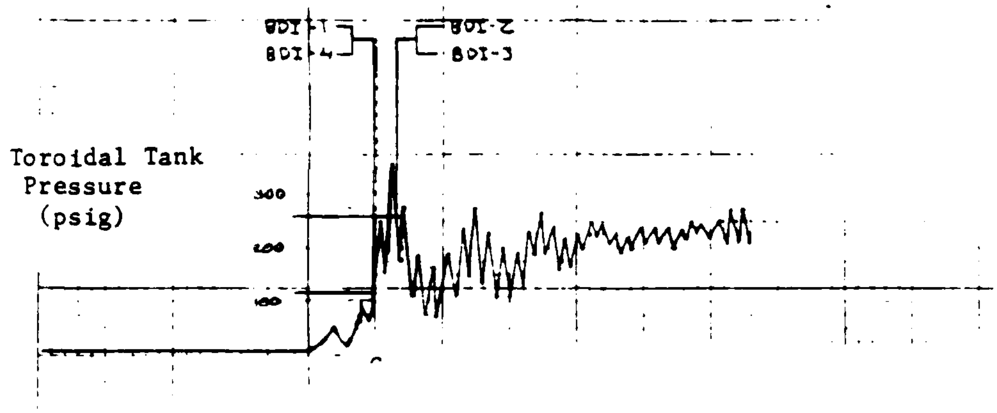


Figure 62. Original Trace and Superimposed Pressure Transients for System ABB-0535

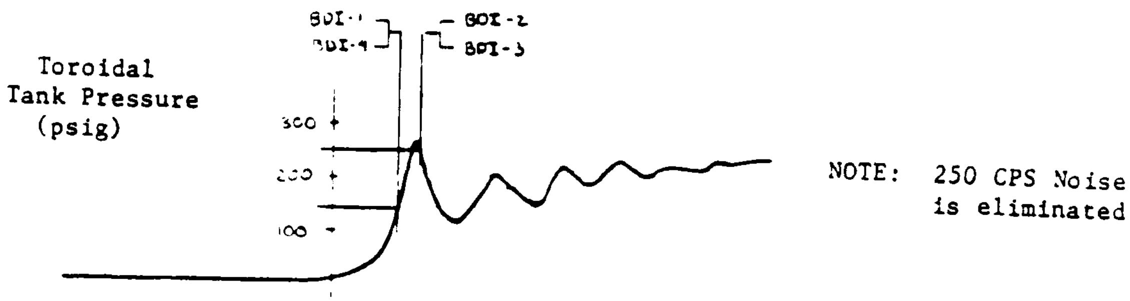
1. <u>System ABB-0535</u>

The pressure-time trace of AAB-0535 shows noise composed of two superimposed frequencies of 250 and 50 cycles per sec. Since these frequencies are low enough to be mechanical, 50 cps noise is probably due to pressure surges in the Freon, and 250 cps noise is probably due to mechanical ringing of the pressure transducer or ringing of the toroidal tank. Second level curve smoothing was required to bring system ABB-0535 within specification. Figure 63 shows progressive elimination of system noise by curve smoothing.

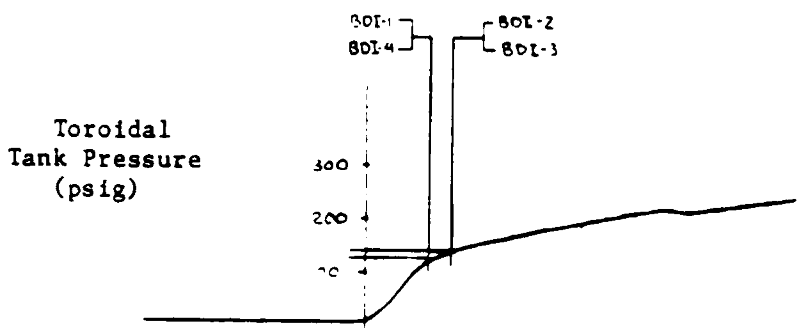
VII.F. TVC Tank and Components (TP-A59) (Cont)



Copy of Original Oscillograph Trace ABB-0535



First Level Curve Smoothing of System ABB-0535



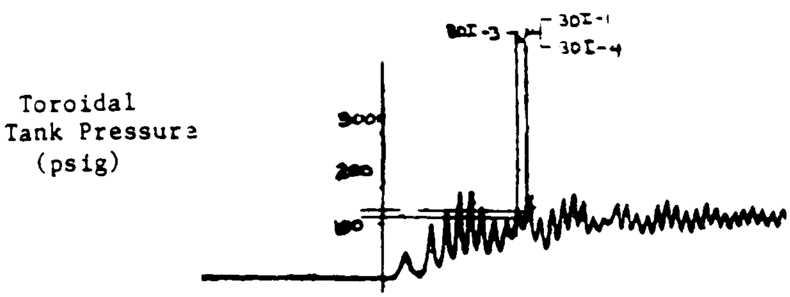
Second Level Curve Smoothing of System ABB-0535

Figure 63. Progressive Elimination of System Noise by Curve Smoothing

VII.F. TVC Tank and Components (TP-A59) (Cont)

2. System AAB-0469

To reduce test system noise, system AAB-0469 was tested at 650 psi per sec cold gas flow rate instead of 700 psi per sec. This lower flow rate was obtained by inserting an orifice in the cold gas supply line. The result was a reduction of the 50 cps noise and an amplitude decrease of the 250 cps noise. No curve smoothing was required for system AAB-0469 to meet specification (Figure 64). The disadvantage of decreasing flow rate is that one burst disc did not burst until 0.6 sec after the other three discs had burst. This lag is not representative of how an operational system would behave with a 650 psi per sec flow rate, but is a consequence of test design. The time lag was not considered during system analysis since it is not detrimental to performance. Burst pressure of the lagging disc was within specification.



NOTE: Curve Smoothing is not required.
Disc-3 Burst 6 Sec after Discs 1, 2, & 4

Original Oscillograph Trace

Figure 64. Pressure Trace of System ABB-0469

Data from previous cold gas flow testing and previous burst disc testing was used for analysis of burst pressure aging trends. Statistical analysis of all available data shows that the effect of age on burst pressure does not jeopardize TVC service life. Result summary is shown in the following table. (See Appendix C, Figures C-22 and C-23, for analysis and data used for analysis.)

VII.F. TVC Tank and Components (TP-A59) (Cont)

1985 COLD GAS FLOW RESULT SUMMARY

Syst SN	Tank SN	Age, mo	Burst Disc, No.	Burst Pressure, psig, Recorded	Smoothed 1st Order	Smoothed 2nd Order	Bladder Vendor
AA-0469	ABB-0077	288	1	120	140	125	Arrowhead
			2	260	250	140	
			3	260	250	140	
			4	120	140	125	
						$\bar{X}$ = 133	
AAB-0535	ABB-0535	230	1	125			US Rubber
			2	120			
			3	112			
			4	125			
				$\bar{X}$ = 121			

References

1. AUE-2PP1 Minuteman Stage II Service Life Analysis Propellant and Propellant-Liner-Insulation, 10 January 1980.

2. AUE-2PP2 Minuteman Stage II Service Life Analysis Component System Surveillance, 10 March 1980.

3. Program Plan for Ignition Delay Investigation of Minuteman ANB-3066 Propellant, 20 September 1979.

4. AUE-2PP2 Appendix A - Plan for Investigation of Minuteman Second Stage LITVC Injectant Bladder Cracking (Aged Motors), November 1979.

5. Interim Engineering Report, Aging and Surveillance Program III Stage II Program Progress Report 0162-06-SAAS-24, April 1980. Appendix A - Surface Hardening Kinetics, 30 May 1980. Appendix B - Ignition Delay Investigation of Minuteman ANB-3066 Propellant, Contract F42600-80-D-4416, 30 May 1980.

6. Minuteman Stage II Service Life Analysis Appendix B - Ignition Delay Investigation, Contract F42600-81-C-4713, 1 July 1981.

7. Final Report, Determination of Propellant Moisture Level in Sealed Motors and Resulting Surface Hardening, Contract F42600-81-5211, March 1985.

8. Program Plan ATF-II-SLA-1, Minuteman Second Stage Remanufacture Program, Service Life Analysis Program, December 1984.

9. Interim Engineering Report, Aging and Surveillance Program III Stage II Program Progress Report 0162-06-SAAS-18, April 1977.

10. MANPA Report NR 473 (82), OO-ALC, August 1982.

11. K.W. Bills, Jr. and L.P. Trimberger "Manufacturing Variables Study of the Minuteman Stage II Motor - Action Item 269," April 23, 1976

Appendix A

Mechanical and Chemical Properties of Materials from Motors

Appendix A contains detailed tabulations of results for mechanical and chemical testing conducted on materials removed from motors. Included are results for remnants from Motors AA20846 and AA20013, excised samples from six field-returned motors, and plugs removed from Motor MSEX-2.

Summaries of visual inspections and nondestructive testing conducted on field-returned motors are also included, as well as preliminary results for the early age-out investigation.

Test Temp, °F	Strain Rate, min^{-1}	Pressure, psig	Property	Storage Time, Months 117*	169	180	204	234
0	0.74	Atm	σ_m, psi		219		229	217
			ϵ_m, %		13		16	14
			ϵ_b, %		22		23	22
			E_o, psi		3500		4350	2961
			SA		60		69	64
40	0.74	Atm	σ_m, psi		159		177	161
			ϵ_m, %		14		14	14
			ϵ_b, %		20		19	17
			E_o, psi		2160		2808	1926
			SA		63		69	64
77	0.74	Atm	σ_m, psi	137	134	134	149	137
			ϵ_m, %	15	14	15	14	14
			ϵ_b, %	18	19	16	16	18
			E_o, psi	1748	1543	1490	1952	1453
			SA	-	62	63	68	62
110	0.74	Atm	σ_m, psi		109		127	114
			ϵ_m, %		14		14	13
			ϵ_b, %		19		16	17
			E_o, psi		1178		1658	1276
			SA		61		69	64
77	0.00018	Atm	σ_m, psi		77		89	96
			ϵ_m, %		12		10	11
			ϵ_b, %		12		10	11
			E_o, psi		708		988	875
			SA		62		68	63
77	100	600	σ_m, psi		428	470	465	435
			ϵ_m, %		26	22	24	24
			ϵ_b, %		28	29	26	27
			E_o, psi		2953	3022	3420	3110
			SA		63	63	65	67

* Sample removed from forward bore; later samples removed from mid-barrel.

Figure A-1. Effect of Test Temperature, Strain Rate and Superimposed Pressure on Uniaxial Tensile Properties of ANB-3066 Propellant from Dissected Motor AA20013

Stage: II
Motor: AA20846
CTPB: Phil

Test Temp, °F	Strain Rate, Min^{-1}	Press psig	Properties	174 Sect 5	146 Sect 2, Seg D	122 Sect 2, Seg B	98 Sect 2, Seg D2	85 Sect 2, Seg E
				Storage Time, Mos.				
0	0.74	Atm	σ_m, psi	249	267		247	
			ϵ_m, %	14	12		17	
			ϵ_b, %	26	23		29	
			E_o, psi	3363	3852		2850	
			SA	60	-		64	
40	0.74	Atm	σ_m, psi	169	187		171	
			ϵ_m, %	17	15		19	
			ϵ_b, %	26	18		28	
			E_o, psi	1550	2053		1580	
			SA	60	-		63	
77	0.74	Atm	σ_m, psi	133	148	146	139	136
			ϵ_m, %	17	16	14	22	17
			ϵ_b, %	25	22	18	30	27
			E_o, psi	1188	1453	1732	1047	1419
			SA	62	63	63	64	62
110	0.74	Atm	σ_m, psi	116	128		114	
			ϵ_m, %	19	17		21	
			ϵ_b, %	26	20		27	
			E_o, psi	943	1164		850	
			SA	63	-		64	
77	0.0005	Atm	σ_m, psi	80	95		76	
			ϵ_m, %	17	14		18	
			ϵ_b, %	18	14		19	
			E_o, psi	565	771		477	
			SA	61	-		63	
77	100	600	σ_m, psi	433	492	476	446	425
			ϵ_m, %	31	27	27	31	31
			ϵ_b, %	37	30	29	37	37
			E_o, psi	3153	3460	3473	2601	2934
			SA	63	-	64	64	62

Figure A-2. Effect of Test Temperature, Strain Rate, and Superimposed Pressure on Uniaxial Tensile Properties of ANB-3066 Propellant from Dissected Motor AA20846

Type Specimen: Mini Uniaxial Tensile
Test Temperature: 77°F

Strain Rate: 1.0 Min^{-1}

Motor Remnant	CTPB	Storage Time, Months	Property	Distance from Bore, Inches 0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.5	2.0
AA20013	CTR	169	σ_m, psi	99	85	81	88	92	96	99	100	101	104	104	107
			ϵ_m, %	21	22	24	24	23	24	23	23	24	23	24	23
			ϵ_b, %	24	24	29	26	25	27	26	26	27	26	25	26
			E_o, psi	687	550	521	590	602	603	618	627	592	650	617	670
		180	σ_m, psi	93	87	88	88	92	94	99	101	104	104	109	107
			ϵ_m, %	20	23	25	23	24	23	24	23	23	24	23	23
			ϵ_b, %	23	28	29	27	28	27	27	27	26	27	26	27
			E_o, psi	708	572	577	634	667	694	692	686	705	705	721	689
		204	σ_m, psi	100	89	90	92	94	98	102	104	105	106	112	114
			ϵ_m, %	17	22	22	22	22	22	22	23	23	21	23	22
			ϵ_b, %	19	27	26	27	25	26	25	27	27	26	26	26
			E_o, psi	988	660	703	730	756	788	786	804	792	824	740	755
		234	σ_m, psi	96	90	92	94	94	99	102	106	108	112	121	118
			ϵ_m, %	18	21	21	20	20	21	22	21	22	21	23	24
			ϵ_b, %	20	28	26	26	26	27	25	25	25	24	27	26
			E_o, psi	748	626	673	744	760	761	767	788	796	800	782	770

Note: Samples for all storage intervals removed from mid-barrel of motor.

Figure A-3. Effect of Distance from Bore on Mini Uniaxial Tensile Properties of ANB-3066 Propellant from Dissected Motor AA20013

Type Specimen: Mini Uniaxial Tensile

Strain Rate, Min^{-1}: 1.0

Test Temperature: 77°F

Motor Remnant	CTPB	Storage Time, Months	Tensile Properties	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.5	2.0	2.5	3.0
				Distance from Bore, Inches													
AA20846	Phil	85	σ_m, psi	138	122	130	134	140	134	133	136	133	130	111	110		
			ϵ_m, %	14	16	16	16	17	17	17	18	19	19	24	24		
			ϵ_b, %	17	17	17	20	20	21	21	22	21	22	34	32		
			E_o, psi	1276	1068	1081	1064	1082	1010	978	962	962	919	642	665		
		98	σ_m, psi	153	149	151	154	154	155	155	156	154	153	126	124	124	125
			ϵ_m, %	14	16	16	15	15	15	16	16	16	16	23	25	24	24
			ϵ_b, %	18	20	19	20	19	19	20	18	18	19	29	34	30	29
			E_o, psi	1575	1342	1392	1438	1438	1438	1375	1350	1362	1275	815	770	750	762
		122	σ_m, psi	153	144	146	147	148	148	147	144	144	137	97	101		
			ϵ_m, %	[illegible]	15	14	14	15	15	16	16	15	16	26	28		
			ϵ_b, %	16	19	18	18	17	18	20	19	18	19	40	40		
			E_o, psi	1932	1597	1614	1507	1473	1474	1402	1315	1402	1336	656	672		
		146	σ_m, psi	166	153	156	156	159	158	157	158	154	152	118	116	113	119
			ϵ_m, %	13	14	14	15	15	15	16	16	16	16	26	28	28	26
			ϵ_b, %	18	21	21	20	20	20	20	20	20	22	35	39	37	36
			E_o, psi	2020	1703	1704	1634	1596	1552	1492	1476	1400	1348	741	699	672	758
		174	σ_m, psi	149	145	150	152	153	154	156	157	157	156	122	108		
			ϵ_m, %	13	15	14	14	13	14	14	14	13	14	23	24		
			ϵ_b, %	18	22	21	20	19	20	19	19	19	19	36	38		
			E_o, psi	1791	1562	1592	1629	1650	1674	1689	1688	1681	1659	727	714		

Figure A-4. Effect of Distance from Bore on Mini Uniaxial Tensile Properties of ANB-3066 Propellant from Dissected Motor AA20846

Type Specimen: Stress Relaxation
Test Temperature: 77°F

Applied Strain: 2.0%

Motor Remnant	CTPB	Storage Time, Months	Property	Distance from Bond, Inches 0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.5	2.0
AA20013	GTR	169	E_{r_1}	1068	711	606	504	541	505	521	534	528	592	613	656
			$E_{r_{10}}$	868	571	490	433	445	417	432	448	436	498	505	536
		204	E_{r_1}	1549	716	574	562	511	562	576	606	635	648	606	-
			$E_{r_{10}}$	1219	596	488	470	434	481	489	509	534	549	516	-
		234	E_{r_1}	464	354	294	282	268	295	362	348	404	432	395	448
			$E_{r_{10}}$	368	270	228	220	217	238	282	276	329	346	331	364

Note: Samples for all storage intervals removed from mid-barrel of motor.

Figure A-5. Effect of Distance from Bond on Relaxation Properties of ANB-3066 Propellant from Dissected Motor AA20013

Type Specimen: Mini Stress Relaxation

Test Temperature: 77°F

Applied Strain: 2.0%

Motor Remnant	CTPB	Storage Time, Months	Tensile Properties	Distance from Bondline, Inches 0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.5	2.0	2.5	3.0
AA20846	Phil	98	E_{r_1}, psi	860	458	390	402	395	392	428	461	468	471	493	540	601	634
			$E_{r_{10}}$, psi	647	356	294	324	313	301	340	364	370	376	393	430	482	502
		146	E_{r_1}, psi	818	511	436	441	405	460	453	450	470	510	582	591	642	546
			$E_{r_{10}}$, psi	649	408	334	342	322	354	360	360	377	402	474	463	512	432
		174	E_{r_1}, psi	1346	1173	742	620	576	627	605	585	656	672	695	797	737	
			$E_{r_{10}}$, psi	1066	923	554	464	434	472	464	449	500	518	535	614	569	

Figure A-6. Effect of Distance from Bond on Relaxation Properties of ANB-3066 Propellant from Dissected Motor AA20846

Test	Test Temp, °F	x-head in./min	Pressure, psig	Type Specimen	Property			
					Age, Months →	169	204	234
					Specimen Location(1) (Section No.)	3A	3A	3A
High Rate Bond Shear	77	10	600	Poker Chip	τ, psi	122	122	
					time, seconds	7.5	7.5	
		100	600		τ, psi	174	174	
					time, seconds	0.9	1.04	
		1000	600		τ, psi	238	220	247
					time, seconds	0.10	0.10	0.11
Constant Rate Bond Tensile	77	1.0	-	DPT	σ_m, psi	102	103	56,108
					time, minutes	0.08	0.12	0.17
Constant Load Bond Tensile	77	-	-	Poker Chip Sleeve	time to failure (minutes) at a given stress:			
					70			
					65		38	
					60		156	
					50			
					47			
					45			0.5
					40		574	
					37.5			
					35			
					30		24,124	141,186

Figure A-7. Summary of Bond Strength for Remnants from Stage II Dissection Motor AA20013

Test	Test Temp, °F	x-head, in./min	Pressure, psig	Type Specimen	Property	98	146	174
					Age, Months →	98	146	174
					Specimen Location[(1)] → (Section No.)	2	2	5
High Rate Bond Shear	77	10	600	Poker Chip	τ, psi	111	112	99
					time, seconds	9.38	9.41	8.29
		100	600		τ, psi	150	189	137
					time, seconds	0.95	1.02	0.89
		1000	600		τ, psi	189	210	194
					time, seconds	0.10	0.115	0.102
Constant Rate Bond Tensile	77	1.0	-	DPT	σ_m, psi	107	101	100
					time, minutes	0.123	0.167	0.177
Constant Load Bond Tensile	77	-	-	Poker Chip Sleeve	time to failure (minutes) at a given stress:			
					70	2.5		
					65	51.4		
					60	423		
					50	1812	23	
					47	847		
					45		6445	
					40	8089	1851	
					37.5		46,886	
					35		27,779	

Figure A-8. Summary of Bond Strength for Remnants from Stage II Dissection Motor AA20846

Cast Date: 2-67
Lot Combination: 20 (GTR)

PROPELLANT

Test Temp., °F	77	77
Crosshead Rate, in./min	1.0	0.5
Applied Strain, %	-	2.0

Distance From Bore Surface, in.	UNIAXIAL TENSILE σ_m, psi	ε_m, %	ε_b, %	E_o, psi	SA	RELAXATION MODULUS, E_r, psi RELAXATION TIME, MINUTES 0.1	1.0	10.0
Surface					67			
0.1	128	17.0	21.0	1158	63			
0.2	122	20.0	26.4	950	66			
0.3	128	20.1	27.4	976	65			
0.4	128	20.1	26.8	965	64			
0.5	128	18.8	27.9	1014	65			
0.6	127	18.1	25.7	1050	66			
0.7	130	18.8	24.9	1066	65			
0.8	128	18.6	27.2	1011	64			
0.9	126	20.0	28.2	987	65			
1.0	127	19.6	27.0	1006	63			
1.5	128	19.0	26.0	1010	65			
2.0	126	18.8	27.2	1014	65			
Distance From Bond Surface, in.								
Surface					57			
0.1	108	16.8	20.6	952	66	729	462	358
0.2	120	19.6	26.8	944	65	734	443	342
0.3	122	20.7	28.8	899	64	692	428	324
0.4	120	21.0	29.8	892	64	624	379	300
0.5	122	20.5	30.1	912	63	618	382	297
0.6	124	20.8	29.0	900	64	618	392	303
0.7	122	20.6	28.8	902	64	653	412	318
0.8	120	21.0	30.2	870	64	620	386	296
0.9	121	20.7	27.3	886	64	654	410	314
1.0	122	20.3	29.6	910	63	663	424	331
1.5	124	20.0	27.7	910	64	710	462	363
2.0	122	20.6	28.6	896	64	670	448	353

INSULATION

Test Temp., °F	77
Crosshead Rate in./min	1.0
Applied Strain %	2.0

	RELAXATION MODULUS, E_r, psi RELAXATION TIME, MINUTES		
	2740	2175	1867
	2659	2136	1809
X	2700	2156	1838

PROPELLANT-LINER-INSULATION

Type Test	Test Temp °F		Stress σ_m psi	Time to Failure, Minutes	Type Failure, %
Mini DPT	77		19	0.030	CL
			11	0.022	CL
			34	0.033	90 CL/10 APL
		X	21	0.028	(Sticky Liner)

Figure A-9. Mechanical Properties Results for Excised Samples Removed from Stage II Motor AA20402, Aged 216 Mo.

Cast Date: 3-68
Lot Combination: 27 (GTR)

PROPELLANT

Test Temp., °F	77	77
Crosshead Rate, in./min	1.0	0.5
Applied Strain, %	-	2.0

	UNIAXIAL TENSILE					RELAXATION MODULUS, E_r, psi RELAXATION TIME, MINUTES		
Distance From Bore Surface, in.	σ_m, psi	ϵ_m, %	ϵ_b, %	E_o, psi	SA	0.1	1.0	10.0
Surface					68			
0.1	142	15.7	19.4	1334	62			
0.2	134	22.4	27.4	1139	64			
0.3	138	24.0	29.6	1146	66			
0.4	142	24.0	28.2	1146	65			
0.5	142	24.2	28.2	1117	66			
0.6	142	24.0	29.4	1102	67			
0.7	142	24.2	27.6	1124	67			
0.8	140	24.2	27.9	1117	64			
0.9	140	24.0	29.2	1124	69			
1.0	138	19.8	22.6	1131	66			
1.5	141	20.9	27.0	1139	67			
2.0	140	19.6	27.2	1176	66			
Distance From Bond Surface, in.								
Surface					69			
0.1	116	11.8	12.7	1262	65	929	615	484
0.2	120	23.8	27.9	854	67	572	345	263
0.3	121	24.6	29.4	838	66	570	351	269
0.4	123	24.6	30.2	838	65	638	380	284
0.5	124	24.8	30.7	831	66	614	380	283
0.6	126	24.6	29.9	853	65	626	390	297
0.7	124	24.2	28.4	838	66	620	390	290
0.8	126	24.0	28.2	862	66	646	397	301
0.9	128	24.7	29.8	891	65	610	382	294
1.0	130	24.4	30.6	891	66	654	406	308
1.5	132	22.4	28.4	929	63	672	427	330
2.0	130	22.5	27.7	920	65	640	414	318

INSULATION

Test Temp., °F	77
Crosshead Rate in./min	1.0
Applied Strain %	2.0

	RELAXATION MODULUS, E_r, psi RELAXATION TIME, MINUTES		
	2079	1715	1521
	2384	1993	1759
X	2232	1854	1640

PROPELLANT-LINER-INSULATION

Type Test	Test Temp °F		Stress σ_m psi	Time to Failure, Minutes	Type Failure, %
Mini DPT	77		40	0.46	CL
			42	0.38	70 CL/30 APL
			39	0.47	80 CL/20 APL
		X	40	0.44	

Figure A-10. Mechanical Properties Results for Excised Samples Removed from Stage II Motor AA20530, Aged 203 Mo.

Cast Date: 10-69
Lot Combination: 29 (GTR)

PROPELLANT

Test Temp., °F	77	77
Crosshead Rate, in./min	1.0	0.5
Applied Strain, %	-	2.0

Distance From Bore Surface, in.	UNIAXIAL TENSILE σ_m, psi	ϵ_m, %	ϵ_b, %	E_o, psi	SA	RELAXATION MODULUS, E_r, psi — RELAXATION TIME, MINUTES 0.1	1.0	10.0
Surface					67			
0.1	99	19.8	24.2	897	63			
0.2	122	23.7	30.5	955	64			
0.3	115	23.3	33.1	905	63			
0.4	111	24.0	30.3	866	65			
0.5	114	23.3	30.7	905	64			
0.6	117	23.3	30.5	919	64			
0.7	117	23.8	30.3	904	66			
0.8	111	22.8	28.3	845	68			
0.9	122	23.1	30.5	933	68			
1.0	109	23.1	29.2	859	65			
1.5	115	21.6	27.0	859	64			
2.0	119	21.3	28.6	919	65			
Distance From Bond Surface, in.								
Surface					63			
0.1	117	13.3	14.0	1172	65	886	600	475
0.2	109	20.7	27.0	919	66	598	366	280
0.3	113	22.9	29.9	861	66	526	330	256
0.4	104	21.8	29.9	786	67	509	326	256
0.5	109	23.3	28.8	816	67	570	366	286
0.6	107	22.9	30.7	799	66	584	372	287
0.7	115	23.6	30.7	844	65	492	313	246
0.8	118	22.9	29.6	874	65	523	338	264
0.9	111	22.5	29.6	799	64	481	311	245
1.0	120	22.9	29.6	888	66	527	339	266
1.5	115	23.3	30.3	816	62	551	359	284
2.0	121	21.8	27.0	888	63	579	378	298

INSULATION

Test Temp., °F	77
Crosshead Rate in./min	1.0
Applied Strain %	2.0

	RELAXATION MODULUS, E_r, psi — RELAXATION TIME, MINUTES		
	2975	2274	1871
	2805	2198	1863
X	2890	2236	1867

PROPELLANT-LINER-INSULATION

Type Test	Test Temp °F		Stress σ_m psi	Time to Failure, Minutes	Type Failure, %
Mini DPT	77		49	0.49	70 APL, 30 CL
			48	0.50	75 APL, 25 CL
			27	0.51	25 APL, 75 CL
		X	41	0.50	

Figure A-11. Mechanical Properties Results for Excised Samples Removed from Stage II Motor AA20596, Aged 180 Mo.

Cast Date: 12-68
Lot Combination: 30 (Phillips)

PROPELLANT

Test Temp., °F	77	77
Crosshead Rate, in./min	1.0	0.5
Applied Strain, %	-	2.0

	UNIAXIAL TENSILE					RELAXATION MODULUS, E_r, psi RELAXATION TIME, MINUTES		
Distance From Bore Surface, in.	σ_m, psi	ϵ_m, %	ϵ_b, %	E_o, psi	SA	0.1	1.0	10.0
Surface					77			
0.1	170	12.6	14.4	1955	75			
0.2	163	14.2	19.0	1584	77			
0.3	162	14.4	18.4	1576	75			
0.4	158	15.1	19.4	1458	75			
0.5	158	14.8	17.6	1466	74			
0.6	156	15.0	18.3	1444	72			
0.7	156	14.8	18.4	1422	74			
0.8	155	15.5	19.4	1428	74			
0.9	154	15.0	18.4	1444	75			
1.0	156	14.8	19.4	1481	72			
1.5	146	15.6	20.3	1296	72			
2.0	118	21.4	32.3	858	73			
Distance From Bond Surface, in.								
Surface					65			
0.1	132	14.4	16.6	1280	73	1226	818	647
0.2	142	16.8	22.0	1206	74	1158	711	534
0.3	150	15.4	19.6	1436	76	1468	942	718
0.4	150	14.6	17.5	1502	72	1510	972	746
0.5	150	14.4	19.0	1444	73	1521	1000	764
0.6	150	14.2	18.0	1472	72	1526	960	763
0.7	152	15.1	19.4	1504	71	1596	993	791
0.8	146	14.6	17.5	1406	72	1546	1004	765
0.9	150	15.0	17.9	1435	71	1500	980	746
1.0	150	15.0	19.0	1435	71	1538	1008	787
1.5	128	19.4	29.0	931	70	1014	609	455
2.0	107	24.2	37.1	679	70	688	380	278

INSULATION

Test Temp., °F	77
Crosshead Rate in./min	1.0
Applied Strain %	2.0

	RELAXATION MODULUS, E_r, psi RELAXATION TIME, MINUTES		
	2383	1909	1662
	2083	1645	1416
X	2233	1777	1539

PROPELLANT-LINER-INSULATION

Type Test	Test Temp °F		Stress σ_m psi	Time to Failure, Minutes	Type Failure, %
Mini DPT	77		40	0.424	CL (Sticky Liner)
			51	0.462	
			27	0.310	
		X	39	0.399	

Figure A-12. Mechanical Properties Results for Excised Samples Removed from Stage II Motor AA20613, Aged 194 Mo.

Cast Date: 1-69
Lot Combination: 32 (Phillips)

PROPELLANT

	Uniaxial Tensile	Relaxation
Test Temp., °F	77	77
Crosshead Rate, in./min	1.0	0.5
Applied Strain, %	-	2.0

Distance From Bore Surface, in.	σ_m, psi	ϵ_m, %	ϵ_b, %	E_o, psi	SA	Relaxation Modulus, E_r, psi — Relaxation Time, Minutes 0.1	1.0	10.0
Surface					71			
0.1	148	11.8	15.9	1798	69			
0.2	145	13.4	20.2	1570	70			
0.3	148	14.2	20.1	1503	68			
0.4	148	15.1	20.5	1442	69			
0.5	147	14.8	17.9	1380	71			
0.6	148	15.7	20.5	1362	68			
0.7	150	16.0	21.0	1316	69			
0.8	136	16.4	22.2	1166	69			
0.9	142	17.2	22.4	1210	69			
1.0	136	18.4	24.0	1109	68			
1.5	117	21.8	32.4	886	69			
2.0	97	25.0	42.8	652	69			
Distance From Bond Surface, in.								
Surface					59			
0.1	102	12.4	13.6	1095	66	898	596	470
0.2	132	15.6	22.2	1220	66	1156	734	580
0.3	140	15.2	20.6	1346	66	1094	716	570
0.4	139	14.8	20.6	1336	66	1256	828	650
0.5	138	15.0	19.0	1362	68	1337	874	678
0.6	137	16.0	21.0	1266	66	1214	791	618
0.7	137	15.3	21.0	1248	67	1144	740	576
0.8	135	16.0	19.8	1224	65	1079	702	541
0.9	136	16.4	22.4	1218	66	1196	770	596
1.0	138	15.8	21.6	1239	64	1184	774	594
1.5	114	22.0	31.8	832	68	982	609	468
2.0	102	25.8	41.8	648	68	758	450	340

INSULATION

Test Temp., °F 77
Crosshead Rate in./min 1.0
Applied Strain % 2.0

	Relaxation Modulus, E_r, psi — Relaxation Time, Minutes		
	3035	2395	2106
	3030	2416	2085
X	3032	2406	2096

PROPELLANT-LINER-INSULATION

Type Test	Test Temp °F		Stress σ_m psi	Time to Failure, Minutes	Type Failure, %
Mini DPT	77		25	0.059	CL (Sticky Liner)
			38	0.048	CL (Sticky Liner)
			42	0.037	CL (Sticky Liner)
		X	35	0.048	CL (Sticky Liner)

Figure A-13. Mechanical Properties Results for Excised Samples Removed from Stage II Motor AA20629, Aged 196 Mo.

Cast Date: 7-74
Lot Combination: 60 (GTR)

PROPELLANT		
Test Temp., °F	77	77
Crosshead Rate, in./min	1.0	0.5
Applied Strain, %	-	2.0

Distance From Bore Surface, in.	σ_m, psi	ϵ_m, %	ϵ_b, %	E_o, psi	SA	Relaxation Modulus, E_r, psi — Relaxation Time, Minutes 0.1	1.0	10.0
Surface					65			
0.1	102	20.1	24.2	820	60			
0.2	100	24.0	32.0	696	62			
0.3	101	25.1	32.9	703	63			
0.4	104	24.4	33.4	689	63			
0.5	103	24.4	32.7	674	65			
0.6	104	25.7	31.4	666	63			
0.7	102	24.6	34.2	666	65			
0.8	101	24.6	35.3	666	65			
0.9	102	24.4	32.9	680	64			
1.0	103	24.8	32.6	704	64			
1.5	106	22.8	30.5	748	59			
2.0	108	23.6	31.2	791	59			
Distance From Bond Surface, in.								
Surface					50			
0.1	65	9.8	10.7	755	64	-	-	-
0.2	96	20.3	29.4	843	63	554	350	274
0.3	98	23.8	31.8	711	65	391	256	198
0.4	97	24.0	30.8	704	62	408	258	205
0.5	99	24.4	32.3	704	63	421	268	212
0.6	99	24.8	31.6	689	63	428	274	218
0.7	100	24.4	33.2	689	61	407	264	216
0.8	101	24.8	32.7	696	61	449	288	234
0.9	102	25.1	32.5	696	61	430	282	224
1.0	102	24.2	31.8	704	62	444	290	228
1.5	102	25.2	33.4	689	60	518	340	270
2.0	104	24.2	33.2	703	60	516	342	277

(Columns σ_m through SA are under the heading UNIAXIAL TENSILE.)

INSULATION	
Test Temp., °F	77
Crosshead Rate in./min	1.0
Applied Strain %	2.0

	Relaxation Modulus, E_r, psi — Relaxation Time, Minutes		
	2421	1919	1665
	2540	2003	1731
X	2480	1961	1698

PROPELLANT-LINER-INSULATION

Type Test	Test Temp °F		Stress σ_m psi	Time to Failure, Minutes	Type Failure, %
Mini DPT	77		19	0.041	CL
			27	0.037	CL
			12	0.038	CL
		X	19	0.039	

Figure A-14. Mechanical Properties Results for Excised Samples Removed from Stage II Motor AA21321, Aged 138 Mo.

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AA	STAGE2 SN	MOTOR AGE MO	FWD GAP 0	FWD LIFTING 0	FWD LINER	FWD UNBONDS	AFT GAP 180	AFT LIFTING 180	AFT LINER	AFT VOIDS QUANTITY	AP FWD	DISCOLORATION	SHORE A AVG	MOTOR CONDITION
LOT COMBO: 20. CTPB MFGR: GTR														
AA	20402.	211.00	0.100	0.100	SS	YES	0.300	0.100	VSS	15.	NONE	NONE	70.11	VPOOR
# MOTORS IN LOT COMBO: 1	AVG AGE,MO: 211.00	LC AVG SHORE A: 70.11	3 SIGMA-SHORE A:											
LOT COMBO: 24. CTPB MFGR: GTR														
AA	20478.	212.30	0.030	0.010	SS	NO	0.210	0.060	VSS	5.	HEAVY	GRAY	72.33	POOR
AA	20490.	209.80	0.050	0.000	VSS	NO	0.320	0.020	VSS		LIGHT	NORM	71.77	POOR
# MOTORS IN LOT COMBO: 2	AVG AGE,MO: 211.05	LC AVG SHORE A: 72.05	3 SIGMA-SHORE A: 1.19											
LOT COMBO: 26. CTPB MFGR: GTR														
AA	20514.	207.70	0.030	0.010	NORM	NO	0.140	0.060	SS	40.	HEAVY	REDDISH	73.11	POOR
AA	20515.	208.20	0.030	0.000	NORM	NO	0.000	0.000	NORM	20.	LIGHT	NORM	69.66	FAIR
AA	20526.	206.80	0.000	0.000	NORM	NO	0.020	0.000	NORM	30.	LIGHT	NORM	68.99	FAIR
# MOTORS IN LOT COMBO: 3	AVG AGE,MO: 207.57	LC AVG SHORE A: 70.59	3 SIGMA-SHORE A: 6.63											
LOT COMBO: 27. CTPB MFGR: GTR														
AA	20533.	205.80	0.000	0.000	NORM	NO	0.000	0.000	NORM	30.	VHEAVY	NORM	70.99	FAIR
AA	20538.	204.70	0.000	0.000	NORM	NO	0.000	0.000	NORM	6.	NONE	NORM	73.44	FAIR
AA	20542.	205.00	0.000	0.000	NORM	NO	0.000	0.000	NORM	10.	LIGHT	NORM	65.90	FAIR
AA	20548.	205.00	0.030	0.010	NORM	NO	0.000	0.000	NORM	20.	LIGHT	NORM	67.70	FAIR
# MOTORS IN LOT COMBO: 4	AVG AGE,MO: 205.13	LC AVG SHORE A: 69.51	3 SIGMA-SHORE A: 10.09											
LOT COMBO: 28. CTPB MFGR: GTR														
AA	20576.	204.00	0.050	0.050	SS	180	0.300	0.100	SS	25.	LIGHT	NORM	67.50	POOR
AA	20584.	201.00	0.040	0.000	NORM	NO	0.100	0.000	NORM	3.	MEDIUM	SLIGHT RED	65.40	POOR
AA	20586.	203.00	0.040	0.000	SS	0	0.100	0.020	VSS	15.	LIGHT	SLIGHT BROWN	66.90	FAIR
AA	20591.	201.00	0.030	0.010	VSS	NO	0.000	0.000	VSS	8.	HEAVY	NO	66.10	FAIR
# MOTORS IN LOT COMBO: 4	AVG AGE,MO: 202.25	LC AVG SHORE A: 66.48	3 SIGMA-SHORE A: 2.75											
LOT COMBO: 29. CTPB MFGR: GTR														
AA	20543.	207.00	0.010	0.000	NORM	NO	0.010	0.000	SS	20.	LIGHT	RED MOTTLE	65.80	FAIR
AA	20561.	200.80	0.040	0.010	VSS	NO	0.200	0.120	SS	20.	MEDIUM	GRAY	70.22	POOR

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AA	STAGE 2 SN	MOTOR AGE MO	FWD GAP 0	FWD LIFTING 0	FWD LINER	FWD UNBONDS	AFT GAP 180	AFT LIFTING 180	AFT LINER	AFT VOIDS QUANTITY	AP FWD	DISCOLORATION	SHORE A AVG	MOTOR CONDITION
AA	20565.	203.00	0.030	0.000	NORM	NO	0.100	0.000	NORM	5.	MEDIUM	NORM	64.00	FAIR
AA	20572.	203.00	0.040	0.020	NORM	YES	0.000	0.000	NORM	12.	LIGHT	NORM	60.30	FAIR
AA	20574.	200.40	0.030	0.200	SS	YES	0.100	0.010	SS	10.	HEAVY	NORM	70.66	POOR
AA	20575.	199.30	0.040	0.010	VSS	NO	0.100	0.010	VSS	20.	HEAVY	DARK GRAY	68.66	FAIR

MOTORS IN LOT COMBO: 6 AVG AGE,MO: 202.25 LC AVG SHORE A: 66.61 3 SIGMA-SHORE A: 12.07

LOT COMBO: 31. CTPB MFGR: GTR

AA	STAGE 2 SN	MOTOR AGE MO	FWD GAP 0	FWD LIFTING 0	FWD LINER	FWD UNBONDS	AFT GAP 180	AFT LIFTING 180	AFT LINER	AFT VOIDS QUANTITY	AP FWD	DISCOLORATION	SHORE A AVG	MOTOR CONDITION
AA	20662.	193.00	0.110	0.050	STCKY	180	0.100	0.070	SS	10.	HEAVY	NORM	63.90	VPOOR

MOTORS IN LOT COMBO: 1 AVG AGE,MO: 193.00 LC AVG SHORE A: 63.90 3 SIGMA-SHORE A:

LOT COMBO: 32. CTPB MFGR: PHILLIPS

AA	STAGE 2 SN	MOTOR AGE MO	FWD GAP 0	FWD LIFTING 0	FWD LINER	FWD UNBONDS	AFT GAP 180	AFT LIFTING 180	AFT LINER	AFT VOIDS QUANTITY	AP FWD	DISCOLORATION	SHORE A AVG	MOTOR CONDITION
AA	20629.	197.00	0.060	0.000	STCKY	N	0.100	0.010	SS	10.	HEAVY	BRN MOTTLING	72.40	VPOOR
AA	20631.	210.00	0.040	0.000	NORM	O	0.150	0.030	SS	2.	HEAVY	REDDISH	70.50	POOR
AA	20657.	194.00	0.030	0.000	NORM	NO	0.020	0.000	NORM	5.	NONE	REDISH-GREY	71.00	FAIR

MOTORS IN LOT COMBO: 3 AVG AGE,MO: 200.33 LC AVG SHORE A: 71.30 3 SIGMA-SHORE A: 2.95

LOT COMBO: 34. CTPB MFGR: GTR

AA	STAGE 2 SN	MOTOR AGE MO	FWD GAP 0	FWD LIFTING 0	FWD LINER	FWD UNBONDS	AFT GAP 180	AFT LIFTING 180	AFT LINER	AFT VOIDS QUANTITY	AP FWD	DISCOLORATION	SHORE A AVG	MOTOR CONDITION
AA	20706.	187.00	0.040	0.000	SS	O	0.000	0.000	VSS	20.	LIGHT	NORM	65.60	FAIR
AA	20710.	185.80	0.060	0.020	VSS	NO	0.040	0.000	VSS	40.	MEDIUM	REDDISH	64.99	FAIR

MOTORS IN LOT COMBO: 2 AVG AGE,MO: 186.40 LC AVG SHORE A: 65.30 3 SIGMA-SHORE A: 1.29

LOT COMBO: 36. CTPB MFGR: GTR

AA	STAGE 2 SN	MOTOR AGE MO	FWD GAP 0	FWD LIFTING 0	FWD LINER	FWD UNBONDS	AFT GAP 180	AFT LIFTING 180	AFT LINER	AFT VOIDS QUANTITY	AP FWD	DISCOLORATION	SHORE A AVG	MOTOR CONDITION
AA	20717.	188.00	0.020	0.000	SS	O	0.050	0.000	SS	40.	LIGHT	NORM	69.00	FAIR
AA	20725.	183.70	0.040	0.000	NORM	NO	0.000	0.000	NORM	15.	HEAVY	DARK GRAY	67.66	FAIR

MOTORS IN LOT COMBO: 2 AVG AGE,MO: 185.85 LC AVG SHORE A: 68.33 3 SIGMA-SHORE A: 2.84

LOT COMBO: 37. CTPB MFGR: GTR

AA	STAGE 2 SN	MOTOR AGE MO	FWD GAP 0	FWD LIFTING 0	FWD LINER	FWD UNBONDS	AFT GAP 180	AFT LIFTING 180	AFT LINER	AFT VOIDS QUANTITY	AP FWD	DISCOLORATION	SHORE A AVG	MOTOR CONDITION
AA	20740.	181.50	0.020	0.000	NORM	O	0.000	0.000	NORM	4.	NONE	REDDISH	70.44	FAIR

MOTORS IN LOT COMBO: 1 AVG AGE,MO: 181.50 LC AVG SHORE A: 70.44 3 SIGMA-SHORE A:

LOT COMBO: 41. CTPB MFGR: PHILLIPS

AA	STAGE 2 SN	MOTOR AGE MO	FWD GAP 0	FWD LIFTING 0	FWD LINER	FWD UNBONDS	AFT GAP 180	AFT LIFTING 180	AFT LINER	AFT VOIDS QUANTITY	AP FWD	DISCOLORATION	SHORE A AVG	MOTOR CONDITION
AA	20800.	177.00	0.000	0.000	NORM	O	0.000	0.000	NORM	5.	NONE	REDDISH-GREY	80.50	POOR

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AA	STAGE2 SN	MOTOR AGE MO	FWD GAP 0	FWD LIFTING 0	FWD LINER	FWD UNBONDS	AFT GAP 180	AFT LIFTING 180	AFT LINER	AFT VOIDS QUANTITY	AP FWD	DISCOLORATION	SHORE A AVG	MOTOR CONDITION

\# MOTORS IN LOT COMBO: 1 AVG AGE,MO: 177.00 LC AVG SHORE A: 80.50 3 SIGMA-SHORE A:

LOT COMBO: 67. CTPB MFGR: PHILLIPS

AA	21480.	111.00	0.000	0.000	NORM	NO	0.000	0.000	NORM	4.	NONE	NONE	74.20	FAIR

\# MOTORS IN LOT COMBO: 1 AVG AGE,MO: 111.00 LC AVG SHORE A: 74.20 3 SIGMA-SHORE A:

		PHILLIPS MOTORS	GTR MOTORS
COUNT		5	26
MOTOR CONDITION:	FAIR	2	17
	POOR	2	7
	VPOOR	1	2

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AA	STAGE2 SN	MOTOR AGE MO	FWD GAP 0	FWD LIFTING 0	FWD LINER	FWD UNBONDS	AFT GAP 180	AFT LIFTING 180	AFT LINER	AFT VOIDS QUANTITY	AP FWD	DISCOLORATION	SHORE A AVG	MOTOR CONDITION
	LOT COMBO: 4.	CTPB MFGR: PHILLIPS												
AA	20109.	205.00	0.060	0.030	SS	YES	0.150	0.100	SS		LIGHT	DARK GRAY/RED	71.00	POOR
AA	20105.	217.00	0.040	0.000	STCKY	NO	0.020	0.000	SS		HEAVY	RED/GREEN	75.30	POOR
AA	20111.	217.00	0.080	0.000	SS		0.200	0.030	SS	1.	MEDIUM	DARK GRAY/RED	75.89	POOR
AA	20106.	225.00	0.060	0.010	SS	YES	0.320	0.040	SS	1.	NONE	RED/GRAY	79.44	POOR
	# MOTORS IN LOT COMBO: 4	AVG AGE,MO: 216.00						LC AVG SHORE A: 75.41				3 SIGMA-SHORE A: 10.38		
	LOT COMBO: 7.	CTPB MFGR: GTR												
AA	20081.	218.00	0.100	0.020	STCKY	YES	0.220	0.300	STCKY	10.	MEDIUM	DARK GRAY	66.22	VPOOR
	# MOTORS IN LOT COMBO: 1	AVG AGE,MO: 218.00						LC AVG SHORE A: 66.22				3 SIGMA-SHORE A:		
	LOT COMBO: 8.	CTPB MFGR: GTR												
AA	20144.	193.00	0.020	0.000	NORM	NO	0.020	0.000	VSS	1.	HEAVY	NONE	66.80	FAIR
AA	20126.	214.00	0.080	0.000	STCKY	NO	0.230	0.090	STCKY		HEAVY	NONE	70.50	POOR
AA	20114.	220.00	0.060	0.100	VSS	YES	0.180	0.150	SS	12.	MEDIUM	DARK GRAY/RED	65.89	VPOOR
	# MOTORS IN LOT COMBO: 3	AVG AGE,MO: 209.00						LC AVG SHORE A: 67.73				3 SIGMA-SHORE A: 7.32		
	LOT COMBO: 9.	CTPB MFGR: PHILLIPS												
AA	20143.	216.00	0.030	0.000	VSS	NO	0.180	0.100	VSS		LIGHT	REDDISH	78.40	FAIR
AA	20138.	217.00	0.020	0.010	SS	YES	0.250	0.150	VSS		LIGHT	NONE	76.33	FAIR
	# MOTORS IN LOT COMBO: 2	AVG AGE,MO: 216.50						LC AVG SHORE A: 77.37				3 SIGMA-SHORE A: 4.39		
	LOT COMBO: 10.	CTPB MFGR: GTR												
AA	20186.	182.00	0.080	0.030	STCKY	NO	0.000	0.000	NORM	6.	LIGHT	NONE	64.00	POOR
AA	20200.	187.00	0.055	0.000	STCKY	NO	0.030	0.000	NORM	3.	MEDIUM	NONE	70.50	FAIR
AA	20193.	191.00	0.150	0.200	VS		0.050	0.020	STCKY	30.	LIGHT		65.55	VPOOR
AA	20198.	210.00	0.070	0.050	STCKY	YES	0.120	0.010	STCKY	15.	LIGHT	DARK GRAY	65.10	VPOOR
AA	20201.	211.00	0.100	0.000	SS	NO	0.120	0.080	SS	50.	MEDIUM	DARK GRAY	67.66	POOR
AA	20157.	216.00	0.040	0.000	SS		0.180	0.020	SS	20.	NONE	DARK GRAY/RED	65.44	FAIR
	# MOTORS IN LOT COMBO: 6	AVG AGE,MO: 199.50						LC AVG SHORE A: 66.38				3 SIGMA-SHORE A: 7.03		
	LOT COMBO: 11.	CTPB MFGR: GTR												

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AA	STAGE 2 SN	MOTOR AGE MO	FWD GAP 0	FWD LIFTING 0	FWD LINER	FWD UNBONDS	AFT GAP 180	AFT LIFTING 180	AFT LINER	AFT VOIDS QUANTITY	AP FWD	DISCOLORATION	SHORE A AVG	MOTOR CONDITION
AA	20218.	185.00	0.100	0.000	STCKY	NO	0.050	0.000	STCKY	5.	LIGHT	NONE	71.00	FAIR
AA	20321.	185.00	0.120	0.080	VS		0.320	0.100	VS	15.	MEDIUM	DARK GRAY	66.40	VPOOR
AA	20332.	187.00	0.060	0.020	STCKY	YES	0.100	0.100	STCKY	100.	LIGHT	DARK GRAY/RED	62.20	VPOOR
AA	20217.	189.00	0.030	0.020	STCKY	NO	0.200	0.030	STCKY	12.	LIGHT	REDDISH	70.80	POOR
AA	20214.	206.00	0.120	0.020	VS	YES	0.200	0.060	STCKY	20.	NONE	NORM	59.33	VPOOR
AA	20211.	209.00	0.100	0.040	STCKY	NO	0.150	0.100	STCKY	10.	LIGHT	REDDISH	67.30	POOR

\# MOTORS IN LOT COMBO: 6 AVG AGE,MO: 193.50 LC AVG SHORE A: 66.17 3 SIGMA-SHORE A: 13.98

LOT COMBO: 12. CTPB MFGR: PHILLIPS

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AA	STAGE 2 SN	MOTOR AGE MO	FWD GAP 0	FWD LIFTING 0	FWD LINER	FWD UNBONDS	AFT GAP 180	AFT LIFTING 180	AFT LINER	AFT VOIDS QUANTITY	AP FWD	DISCOLORATION	SHORE A AVG	MOTOR CONDITION
AA	20183.	187.00	0.070	0.000	STCKY	NO	0.250	0.030	STCKY	1.	MEDIUM	NONE	77.00	POOR
AA	20166.	204.00	0.080	0.020	STCKY		0.220	0.020	STCKY		NONE		72.10	POOR
AA	20159.	212.00	0.050	0.000	STCKY	NO	0.300	0.150	STCKY		LIGHT	GRAY/BROWN	78.30	POOR

\# MOTORS IN LOT COMBO: 3 AVG AGE,MO: 201.00 LC AVG SHORE A: 75.80 3 SIGMA-SHORE A: 9.81

LOT COMBO: 13. CTPB MFGR: PHILLIPS

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AA	STAGE 2 SN	MOTOR AGE MO	FWD GAP 0	FWD LIFTING 0	FWD LINER	FWD UNBONDS	AFT GAP 180	AFT LIFTING 180	AFT LINER	AFT VOIDS QUANTITY	AP FWD	DISCOLORATION	SHORE A AVG	MOTOR CONDITION
AA	20232.	187.00	0.055	0.000	SS	NO	0.030	0.010	VSS	1.	NONE	NONE	75.40	FAIR
AA	20238.	190.00	0.030	0.000	VSS		0.120	0.050	SS		NONE	DARK GRAY/RED	82.32	FAIR
AA	20235.	200.00	0.070	0.010	SS		0.100	0.150	SS	1.	LIGHT	DARK GRAY	74.40	POOR
AA	20234.	202.00	0.030	0.000	VSS		0.150	0.100	VSS	1.	LIGHT	DARK GRAY/RED	72.33	POOR
AA	20223.	205.00	0.030	0.000	VSS		0.020	0.030	VSS	3.	NONE		72.89	FAIR
AA	20212.	217.00	0.090	0.010	STCKY	YES	0.300	0.140	STCKY	10.	NONE	NONE	78.78	VPOOR

\# MOTORS IN LOT COMBO: 6 AVG AGE,MO: 200.17 LC AVG SHORE A: 76.02 3 SIGMA-SHORE A: 11.52

LOT COMBO: 14. CTPB MFGR: PHILLIPS

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AA	STAGE 2 SN	MOTOR AGE MO	FWD GAP 0	FWD LIFTING 0	FWD LINER	FWD UNBONDS	AFT GAP 180	AFT LIFTING 180	AFT LINER	AFT VOIDS QUANTITY	AP FWD	DISCOLORATION	SHORE A AVG	MOTOR CONDITION
AA	20269.	185.00	0.030	0.000	VSS	NO	0.030	0.000	NORM		NONE	REDDISH	78.00	FAIR
AA	20276.	187.00	0.070	0.040	STCKY		0.030	0.010	SS	3.	LIGHT		77.11	POOR
AA	20283.	188.00	0.020	0.000	SS		0.180	0.030	STCKY	4.	NONE	DARK GRAY	72.80	FAIR
AA	20259.	189.00	0.040	0.000	SS		0.180	0.120	SS	6.	LIGHT		71.50	FAIR

\# MOTORS IN LOT COMBO: 4 AVG AGE,MO: 187.25 LC AVG SHORE A: 74.85 3 SIGMA-SHORE A: 9.56

LOT COMBO: 15. CTPB MFGR: PHILLIPS

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AA	STAGE 2 SN	MOTOR AGE MO	FWD GAP 0	FWD LIFTING 0	FWD LINER	FWD UNBONDS	AFT GAP 180	AFT LIFTING 180	AFT LINER	AFT VOIDS QUANTITY	AP FWD	DISCOLORATION	SHORE A AVG	MOTOR CONDITION
AA	20267.	186.00	0.070	0.000	SS	NO	0.240	0.010	VSS		MEDIUM	DARK GRAY/RED	84.11	POOR
AA	20240.	188.00	0.030	0.010	VSS	NO	0.030	0.030	SS	3.	NONE	REDDISH	82.33	FAIR
AA	20244.	193.00	0.080	0.010	SS	YES	0.260	0.030	STCKY		LIGHT		76.80	POOR
AA	20247.	195.00	0.100	0.020	STCKY	YES	0.210	0.040	VS	1.	LIGHT	DARK GRAY/RED	77.60	VPOOR
AA	20264.	209.00	0.030	0.000	SS		0.080	0.000	VSS	1.	NONE	DARK GRY/BRWN	82.33	POOR
AA	20292.	214.00	0.060	0.030	STCKY	YES	0.600	0.060	STCKY	15.	LIGHT		65.78	VPOOR

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AA	STAGE2 SN	MOTOR AGE MO	FWD GAP 0	FWD LIFTING 0	FWD LINER	FWD UNBONDS	AFT GAP 180	AFT LIFTING 180	AFT LINER	AFT VOIDS QUANTITY	AP FWD	DISCOLORATION	SHORE A AVG	MOTOR CONDITION

MOTORS IN LOT COMBO: 6 AVG AGE,MO: 197.50 LC AVG SHORE A: 78.16 3 SIGMA-SHORE A: 20.15

LOT COMBO: 16. CTPB MFGR: PHILLIPS
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AA	STAGE2 SN	MOTOR AGE MO	FWD GAP 0	FWD LIFTING 0	FWD LINER	FWD UNBONDS	AFT GAP 180	AFT LIFTING 180	AFT LINER	AFT VOIDS QUANTITY	AP FWD	DISCOLORATION	SHORE A AVG	MOTOR CONDITION
AA	20315.	180.00	0.100	0.020	STCKY	NO	0.300	0.100	STCKY		MEDIUM	DARK GRAY	80.00	POOR
AA	20331.	182.00	0.030	0.000	NORM	NO	0.200	0.030	SS	6.	LIGHT	NONE	76.00	POOR
AA	20327.	184.00	0.030	0.010	NORM	NO	0.030	0.030	VSS		LIGHT	NONE	75.77	FAIR
AA	20356.	184.00	0.080	0.030	STCKY		0.100	0.060	SS		LIGHT	DARK GRAY	74.10	POOR
AA	20361.	187.00	0.030	0.010	NORM		0.200	0.100	VSS	2.	NONE	DARK GRAY	66.20	FAIR
AA	20338.	189.00	0.010	0.000	VSS		0.150	0.030	VSS	14.	LIGHT	REDDISH	68.70	FAIR
AA	20335.	193.00	0.030	0.000	VSS		0.250	0.150	VSS	1.	NONE	REDDISH	71.20	FAIR
AA	20353.	198.00	0.030	0.000	NORM		0.280	0.120	SS	10.	NONE	DARK GRAY	68.56	POOR
AA	20337.	199.00	0.010	0.000	NORM		0.210	0.050	STCKY	10.	LIGHT	BROWN/GRAY	71.56	FAIR
AA	20325.	203.00	0.020	0.000	VSS	NO	0.220	0.100	SS		NONE	DARK GRAY	72.80	FAIR
AA	20320.	205.00	0.100	0.010	SS	YES	0.400	0.200	SS	20.	LIGHT	REDDISH	73.20	VPOOR

MOTORS IN LOT COMBO: 11 AVG AGE,MO: 191.27 LC AVG SHORE A: 72.55 3 SIGMA-SHORE A: 11.79

LOT COMBO: 17. CTPB MFGR: PHILLIPS
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AA	STAGE2 SN	MOTOR AGE MO	FWD GAP 0	FWD LIFTING 0	FWD LINER	FWD UNBONDS	AFT GAP 180	AFT LIFTING 180	AFT LINER	AFT VOIDS QUANTITY	AP FWD	DISCOLORATION	SHORE A AVG	MOTOR CONDITION
AA	20296.	180.00	0.030	0.000	STCKY		0.100	0.040	STCKY	6.	LIGHT		68.00	FAIR
AA	20289.	184.00	0.030	0.010	SS	NO	0.030	0.010	STCKY	3.	NONE	NONE	63.20	FAIR
AA	20301.	190.00	0.100	0.050	STCKY	YES	0.180	0.150	STCKY	25.	NONE		61.60	VPOOR
AA	20299.	191.00	0.060	0.000	SS	YES	0.250	0.150	STCKY	10.	LIGHT	DARK GRAY/RED	60.10	POOR
AA	20293.	198.00	0.040	0.010	VSS		0.200	0.030	SS	6.	NONE	DARK GRAY	63.67	FAIR
AA	20300.	200.00	0.060	0.100	VS	YES	0.340	0.100	VS	10.	NONE	DARK GRAY	60.22	VPOOR
AA	20303.	201.00	0.070	0.000	STCKY		0.380	0.020	STCKY		LIGHT	DARK GRAY	65.56	POOR
AA	20291.	203.00	0.040	0.030	STCKY	YES	0.240	0.020	VS	10.	LIGHT	DARK GRAY	61.33	VPOOR
AA	20290.	204.00	0.090	0.010	STCKY	NO	0.280	0.100	STCKY	50.	NONE	NORM	66.90	POOR
AA	20309.	204.00	0.160	0.010	STCKY	YES	0.220	0.200	STCKY	25.	LIGHT	DARK GRAY	62.20	VPOOR

MOTORS IN LOT COMBO: 10 AVG AGE,MO: 195.50 LC AVG SHORE A: 63.28 3 SIGMA-SHORE A: 8.25

LOT COMBO: 18. CTPB MFGR: PHILLIPS
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AA	STAGE2 SN	MOTOR AGE MO	FWD GAP 0	FWD LIFTING 0	FWD LINER	FWD UNBONDS	AFT GAP 180	AFT LIFTING 180	AFT LINER	AFT VOIDS QUANTITY	AP FWD	DISCOLORATION	SHORE A AVG	MOTOR CONDITION
AA	20386.	178.00	0.030	0.010	NORM	NO	0.030	0.010	VSS	6.	MEDIUM	NONE	71.50	FAIR
AA	20352.	182.00	0.070	0.030	SS	NO	0.150	0.030	STCKY	6.	LIGHT	NONE	73.80	POOR
AA	20384.	182.00	0.030	0.000	NORM		0.040	0.010	NORM	8.	NONE	DARK GRAY/RED	75.66	FAIR
AA	20378.	184.00	0.030	0.010	VSS		0.100	0.050	SS	2.	NONE	DARK GRAY	67.80	POOR
AA	20362.	188.00	0.060	0.030	STCKY	YES	0.300	0.100	STCKY	10.	LIGHT	DARK GRAY/RED	66.80	VPOOR
AA	20381.	190.00	0.030	0.000	SS		0.100	0.050	SS	12.	LIGHT	DARK GRAY	69.77	POOR
AA	20383.	192.00	0.200	0.000	NORM		0.100	0.000	NORM	1.	LIGHT		68.00	POOR
AA	20396.	192.00	0.030	0.000	NORM		0.200	0.010	VSS	3.	NONE		66.00	FAIR
AA	20364.	193.00	0.040	0.000	VSS	YES	0.240	0.100	STCKY		NONE	DARK GRAY	70.50	VPOOR
AA	20382.	195.00	0.030	0.000	NORM		0.050	0.000	NORM		NONE	DARK GRAY	71.89	FAIR

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MOTORS IN LOT COMBO: 10 AVG AGE,MO: 187.60 LC AVG SHORE A: 70.17 3 SIGMA-SHORE A: 9.35

LOT COMBO: 19. CTPB MFGR: GTR

AA	STAGE2 SN	MOTOR AGE MO	FWD GAP 0	FWD LIFTING 0	FWD LINER	FWD UNBONDS	AFT GAP 180	AFT LIFTING 180	AFT LINER	AFT VOIDS QUANTITY	AP FWD	DISCOLORATION	SHORE A AVG	MOTOR CONDITION
AA	20357.	180.00	0.040	0.010	NORM	NO	0.000	0.010	SS	9.	HEAVY	NONE	69.00	POOR
AA	20355.	191.00	0.090	0.000	VSS	NO	0.280	0.010	SS	3.	LIGHT	NONE	70.00	POOR
AA	20399.	182.00	0.060	0.000	VSS		0.080	0.010	VSS	15.	NONE	DARK GRAY	63.80	FAIR
AA	20341.	185.00	0.070	0.020	VSS		0.100	0.040	SS	8.	NONE		67.20	FAIR
AA	20392.	186.00	0.030	0.150	NORM	YES	0.200	0.100	SS	30.	NONE		60.00	POOR
AA	20350.	187.00	0.090	0.050	STCKY	YES	0.260	0.140	VS	25.	LIGHT		64.20	VPOOR
AA	20370.	189.00	0.060	0.000	VS	YES	0.400	0.010	VS	20.	LIGHT	DARK GRAY	61.66	VPOOR
AA	20346.	191.00	0.030	0.000	VSS		0.200	0.080	VSS	5.	NONE		63.50	FAIR
AA	20369.	197.00	0.080	0.050	STCKY	YES	0.400	0.010	STCKY	10.	NONE	NONE	62.56	VPOOR
AA	20389.	212.40	0.060	0.010	SS	YES	0.180	0.080	SS	20.	MEDIUM	DARK GRAY/RED	70.78	POOR
AA	20394.	215.00	0.040	0.040	STCKY	YES	0.200	0.080	SS	10.	MEDIUM	DARK GRAY	72.30	VPOOR

MOTORS IN LOT COMBO: 11 AVG AGE,MO: 191.40 LC AVG SHORE A: 65.91 3 SIGMA-SHORE A: 12.37

LOT COMBO: 20. CTPB MFGR: GTR

AA	STAGE2 SN	MOTOR AGE MO	FWD GAP 0	FWD LIFTING 0	FWD LINER	FWD UNBONDS	AFT GAP 180	AFT LIFTING 180	AFT LINER	AFT VOIDS QUANTITY	AP FWD	DISCOLORATION	SHORE A AVG	MOTOR CONDITION
AA	20403.	178.00	0.030	0.010	SS	NO	0.020	0.000	NORM	20.	LIGHT	NONE	70.00	FAIR
AA	20415.	179.00	0.070	0.000	SS	NO	0.250	0.200	SS	12.	NONE	REDDISH	67.60	POOR
AA	20411.	180.00	0.060	0.040	STCKY		0.180	0.200	VSS	3.	MEDIUM	REDDISH	63.80	POOR
AA	20368.	185.00	0.050	0.010	VS		0.400	0.020	STCKY	5.	NONE	DARK GRAY	63.00	POOR
AA	20401.	186.00	0.060	0.020	VS		0.200	0.100	SS	12.	HEAVY	DARK GRAY/RED	63.80	VPOOR
AA	20400.	188.00	0.030	0.010	SS		0.100	0.010	SS	20.	LIGHT	DARK GRAY	65.60	FAIR
AA	20413.	202.00	0.040	0.020	VS	YES	0.350	0.200	VS	30.	LIGHT	NNE	64.30	VPOOR
AA	20409.	209.70	0.060	0.100	VSS	YES	0.180	0.100	VSS	4.	LIGHT	NORM	69.11	VPOOR
AA	20408.	210.00	0.030	0.020	SS	NO	0.200	0.050	SS	6.	LIGHT	NORM	68.22	FAIR
AA	20402.	211.00	0.100	0.100	SS	YES	0.300	0.100	VSS	15.	NONE	NONE	70.11	VPOOR

MOTORS IN LOT COMBO: 10 AVG AGE,MO: 192.87 LC AVG SHORE A: 66.55 3 SIGMA-SHORE A: 8.29

LOT COMBO: 21. CTPB MFGR: PHILLIPS

AA	STAGE2 SN	MOTOR AGE MO	FWD GAP 0	FWD LIFTING 0	FWD LINER	FWD UNBONDS	AFT GAP 180	AFT LIFTING 180	AFT LINER	AFT VOIDS QUANTITY	AP FWD	DISCOLORATION	SHORE A AVG	MOTOR CONDITION
AA	20374.	185.00	0.010	0.000	NORM		0.100	0.010	VSS		NONE	DARK GRAY	69.66	FAIR
AA	20429.	186.00	0.020	0.000	NORM		0.160	0.100	VSS		LIGHT	DARK GRAY/RED	68.80	POOR
AA	20432.	189.00	0.030	0.000	VSS	YES	0.320	0.100	SS	10.	LIGHT	REDDISH	76.50	POOR
AA	20437.	191.00	0.030	0.000	SS		0.250	0.010	SS	1.	MEDIUM	REDDISH	72.67	POOR
AA	20449.	191.00	0.030	0.010	SS		0.300	0.100	STCKY	2.	LIGHT	DARK GRAY	76.11	POOR
AA	20376.	192.00	0.100	0.000	NORM		0.100	0.000	NORM	6.	LIGHT	REDDISH	74.10	FAIR
AA	20446.	192.00	0.050	0.020	SS		0.400	0.250	VSS	10.	LIGHT	REDDISH	74.00	POOR
AA	20377.	200.00	0.010	0.000	VSS	NO	0.000	0.000	VSS		MEDIUM	DARK GRAY/RED	78.30	FAIR
AA	20456.	204.00	0.020	0.000	NORM	NO	0.200	0.080	STCKY		HEAVY	RED SPOTS	81.11	POOR
AA	20454.	205.00	0.030	0.010	VSS	NO	0.220	0.120	SS	10.	LIGHT	DARK GRAY/RED	81.11	VPOOR
AA	20452.	209.00	0.030	0.000	NORM	NO	0.340	0.040	SS		LIGHT	GRAY	77.11	POOR

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AA	STAGE 2 SN	MOTOR AGE MO	FWD GAP 0	FWD LIFTING 0	FWD LINER	FWD UNBONDS	AFT GAP 180	AFT LIFTING 180	AFT LINER	AFT VOIDS QUANTITY	AP FWD	DISCOLORATION	SHORE A AVG	MOTOR CONDITION
# MOTORS IN LOT COMBO: 11		AVG AGE,MO: 194.91					LC AVG SHORE A: 75.41				3 SIGMA-SHORE A: 12.22			
LOT COMBO: 22.		CTPB MFGR: GTR												
AA	[illegible]	174.00	0.030	0.000	SS	YES	0.200	0.100	SS	5.	LIGHT	DARK GRAY/RED	65.30	POOR
AA	20375.	178.00	0.040	0.000	SS	NO	0.150	0.010	STCKY	4.	LIGHT	NONE	74.00	FAIR
AA	20425.	180.00	0.030	0.010	SS		0.040	0.030	SS	15.	NONE		69.80	FAIR
AA	20423.	181.00	0.030	0.010	SS		0.100	0.010	SS	15.	LIGHT		73.50	FAIR
AA	[illegible]	188.00	0.030	0.010	VSS		0.150	0.100	SS	12.	MEDIUM		69.90	POOR
AA	20442.	188.00	0.030	0.010	VSS		0.160	0.120	SS	10.	HEAVY		71.60	VPOOR
AA	20426.	193.00	0.010	0.000	NORM		0.100	0.060	SS	15.	MEDIUM	NONE	68.67	FAIR
AA	20421.	194.00	0.050	0.010	STCKY		0.180	0.100	STCKY	20.	MEDIUM	NONE	67.56	POOR
AA	20438.	210.00	0.060	0.000	SS	YES	0.380	0.100	STCKY		LIGHT	DARK GRAY	72.56	VPOOR
AA	20443.	210.00	0.030	0.040	SS	YES	0.220	0.020	SS	10.	MEDIUM		74.78	VPOOR
# MOTORS IN LOT COMBO: 10		AVG AGE,MO: 189.60					LC AVG SHORE A: 70.77				3 SIGMA-SHORE A: 9.18			
LOT COMBO: 23.		CTPB MFGR: PHILLIPS												
AA	20549.	190.00	0.010	0.000	NORM	NO	0.120	0.020	VSS	6.	LIGHT	REDDISH	79.45	FAIR
AA	20509.	198.00	0.060	0.010	SS	NO	0.200	0.020	STCKY	2.	VHEAVY	REDDISH	78.55	POOR
AA	20482.	199.00	0.010	0.000	VSS	NO	0.100	0.010	VSS	6.	HEAVY	DARK GRAY	79.32	FAIR
AA	20477.	200.00	0.035	0.000	SS	NO	0.300	0.010	SS		HEAVY	BROWN/RED	81.33	POOR
AA	20466.	207.00	0.030	0.000	VSS	NO	0.200	0.080	SS	3.	LIGHT	GRAY/GREEN	84.00	FAIR
AA	20469.	209.00	0.010	0.000	NORM	NO	0.140	0.010	VSS	4.	MEDIUM	RED	81.00	FAIR
# MOTORS IN LOT COMBO: 6		AVG AGE,MO: 200.50					LC AVG SHORE A: 80.61				3 SIGMA-SHORE A: 5.91			
LOT COMBO: 24.		CTPB MFGR: GTR												
AA	20485.	190.00	0.060	0.010	SS	NO	0.180	0.000	STCKY	15.	MEDIUM	BROWN/GRAY	67.00	POOR
AA	20476.	192.00	0.020	0.000	NORM	NO	0.150	0.040	VSS	10.	HEAVY	DARK GRAY/RED	66.22	POOR
AA	20488.	192.00	0.020	0.000	VSS	NO	0.030	0.000	VSS	5.	MEDIUM	DARK GRAY	66.33	FAIR
AA	20473.	194.00	0.030	0.000	SS	NO	0.080	0.030	SS		VHEAVY	DARK GRAY	67.20	VPOOR
AA	20481.	197.00	0.030	0.000	NORM	YES	0.180	0.020	SS	30.	MEDIUM	DARK GRAY	66.10	POOR
AA	20489.	197.00	0.040	0.000	VSS	YES	0.120	0.050	VSS	6.	LIGHT	DARK GRAY	71.78	POOR
AA	20486.	207.50	0.030	0.000	VSS	NO	0.180	0.040	VSS	20.	NONE	NONE	70.67	FAIR
AA	20483.	209.00	0.060	0.000	SS	NO	0.220	0.020	SS	4.	HEAVY	NORM	73.22	POOR
AA	20490.	209.00	0.050	0.000	VSS	NO	0.320	0.020	VSS		LIGHT	NORM	71.77	POOR
AA	20478.	212.30	0.030	0.010	SS	NO	0.210	0.060	VSS	5.	HEAVY	GRAY	72.33	POOR
# MOTORS IN LOT COMBO: 10		AVG AGE,MO: 200.06					LC AVG SHORE A: 69.26				3 SIGMA-SHORE A: 8.77			
LOT COMBO: 25.		CTPB MFGR: PHILLIPS												

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AA	STAGE 2 SN	MOTOR AGE MO	FWD GAP 0	FWD LIFTING 0	FWD LINER	FWD UNBONDS	AFT GAP 180	AFT LIFTING 180	AFT LINER	AFT VOIDS QUANTITY	AP FWD	DISCOLORATION	SHORE A AVG	MOTOR CONDITION
AA	20505.	[illegible]	0.000	0.000	NORM	NO	0.100	0.015	STICKY		MEDIUM	NONE	76.00	FAIR
AA	20498.	178.00	0.000	0.000	STICKY		0.070	0.000	NORM		NONE		71.00	FAIR
AA	20502.	184.00	0.100	0.200	NORM		0.180	0.060	SS	10.	HEAVY	DARK GRAY	72.00	VPOOR
20	20508.	192.00	0.030	0.000	NORM	NO	0.400	0.030	SS	10.	HEAVY	DARK GRAY/RED	78.20	POOR
AA	20510.	192.00	0.020	0.000	NORM		0.100	0.000	VSS		HEAVY	DARK GRAY/RED	76.40	FAIR
AA	20507.	196.00	0.000	0.000	NORM	NO	0.000	0.000	NORM		VHEAVY	REDDISH	80.77	POOR
AA	[illegible]	[illegible]	[illegible]	0.010	VSS	NO	0.080	0.000	VSS		MEDIUM	REDDISH	76.00	FAIR
AA	20501.	[illegible]	0.000	0.000	NORM	NO	0.160	0.100	STCKY		HEAVY	NORMAL	79.40	POOR
AA	[illegible]	[illegible]	0.025	0.000	VSS	NO	0.180	0.080	VSS	6.	MEDIUM	NONE	78.55	FAIR
AA	20457.	[illegible]	0.000	0.000	NORM	NO	0.050	0.000	VSS	1.	LIGHT	GREENISH	82.99	FAIR

MOTORS IN LOT COMBO: 10 AVG AGE,MO: 193.80 LC AVG SHORE A: 77.13 3 SIGMA-SHORE A: 11.09

LOT COMBO: 26. CTPB MFGR: GTR

AA	STAGE 2 SN	MOTOR AGE MO	FWD GAP 0	FWD LIFTING 0	FWD LINER	FWD UNBONDS	AFT GAP 180	AFT LIFTING 180	AFT LINER	AFT VOIDS QUANTITY	AP FWD	DISCOLORATION	SHORE A AVG	MOTOR CONDITION
AA	20535.	181.00	0.000	0.000	NORM		0.000	0.000	NORM	10.	LIGHT		60.77	FAIR
AA	20521.	184.00	0.010	0.000	NORM		0.020	0.000	NORM	50.	MEDIUM	REDDISH	63.78	FAIR
AA	20511.	187.00	0.040	0.000	NORM	NO	0.100	0.020	SS	30.	HEAVY	REDDISH	64.33	FAIR
AA	20518.	188.00	0.020	0.000	VSS	NO	0.030	0.010	SS	50.	VHEAVY	DARK GRAY/RED	67.80	FAIR
AA	20527.	[illegible]	0.000	0.000	VSS	NO	0.000	0.000	VSS	35.	LIGHT	DARK GREY	65.44	FAIR
AA	20532.	[illegible]	0.000	0.000	NORM	NO	0.010	0.000	VSS	50.	LIGHT	GRAY/RED	65.33	FAIR
AA	20493.	199.00	0.040	0.010	VSS	NO	0.080	0.010	VSS	10.	LIGHT	NONE	68.89	FAIR
AA	20495.	199.00	0.080	0.020	VSS	YES	0.140	0.060	SS	3.	LIGHT	RED	65.33	POOR
AA	20523.	200.30	0.040	0.010	VSS	NO	0.380	0.030	SS	12.	MEDIUM	NORM	63.80	FAIR
AA	20519.	201.00	0.000	0.000	NORM	NO	0.000	0.000	NORM	20.	HEAVY	DARK GRAY	68.70	FAIR
AA	20516.	205.30	0.030	0.000	VSS	NO	0.150	0.180	SS	6.	HEAVY	GRAY/RED	70.30	POOR
AA	20526.	206.80	0.000	0.000	NORM	NO	0.020	0.000	NORM	30.	LIGHT	NORM	68.99	FAIR
AA	20514.	207.70	0.030	0.010	NORM	NO	0.140	0.060	SS	40.	HEAVY	REDDISH	73.11	POOR
AA	20515.	208.20	0.030	0.000	NORM	NO	0.000	0.000	NORM	20.	LIGHT	NORM	69.66	FAIR

MOTORS IN LOT COMBO: 14 AVG AGE,MO: 196.81 LC AVG SHORE A: 66.87 3 SIGMA-SHORE A: 9.87

LOT COMBO: 27. CTPB MFGR: GTR

AA	STAGE 2 SN	MOTOR AGE MO	FWD GAP 0	FWD LIFTING 0	FWD LINER	FWD UNBONDS	AFT GAP 180	AFT LIFTING 180	AFT LINER	AFT VOIDS QUANTITY	AP FWD	DISCOLORATION	SHORE A AVG	MOTOR CONDITION
AA	20553.	176.00	0.010	0.000	NORM		0.100	0.000	NORM	30.	LIGHT	REDDISH	63.88	FAIR
AA	20540.	178.00	0.000	0.000	NORM		0.030	0.000	NORM	30.	VHEAVY	REDDISH	67.00	FAIR
AA	20546.	180.00	0.000	0.000	NORM		0.020	0.000	SS	10.	MEDIUM		61.33	FAIR
AA	20544.	184.00	0.000	0.000	NORM	NO	0.030	0.000	NORM	20.	MEDIUM	DARK GRAY/RED	66.90	FAIR
AA	20551.	185.00	0.010	0.000	NORM	NO	0.080	0.000	VSS	1.	LIGHT	REDDISH	65.10	FAIR
AA	20539.	188.00	0.000	0.000	NORM		0.000	0.000	NORM	30.	MEDIUM	REDDISH	62.88	FAIR
AA	20536.	191.00	0.010	0.000	NORM		0.010	0.000	NORM	20.	HEAVY	RED/BROWN	70.11	FAIR
AA	20528.	192.00	0.000	0.000	NORM	NO	0.020	0.000	NORM	15.	LIGHT	DARK GRAY	66.40	FAIR
AA	20534.	199.00	0.030	0.000	NORM	NO	0.000	0.000	NORM	10.	MEDIUM	REDDISH	67.67	FAIR
AA	20530.	203.00	0.000	0.000	NORM	NO	0.000	0.000	VSS	12.	NONE	NORM	72.33	FAIR
AA	[illegible]	204.70	0.000	0.000	NORM	NO	0.000	0.000	NORM	6.	NONE	NORM	73.44	FAIR
AA	[illegible]	[illegible]	0.000	0.000	NORM	NO	0.000	0.000	NORM	10.	LIGHT	NORM	65.90	FAIR
AA	[illegible]	[illegible]	0.030	0.010	NORM	NO	0.000	0.000	NORM	20.	LIGHT	NORM	67.70	FAIR
AA	20533.	205.80	0.000	0.000	NORM	NO	0.000	0.000	NORM	30.	VHEAVY	NORM	70.99	FAIR

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MOTORS IN LOT COMBO: 14 AVG AGE,MO: 192.61 LC AVG SHORE A: 67.26 3 SIGMA-SHORE A: 10.51

LOT COMBO: 28. CTPB MFGR: GTR

AA	STAGE2 SN	MOTOR AGE MO	FWD GAP 0	FWD LIFTING 0	FWD LINER	FWD UNBONDS	AFT GAP 180	AFT LIFTING 180	AFT LINER	AFT VOIDS QUANTITY	AP FWD	DISCOLORATION	SHORE A AVG	MOTOR CONDITION
AA	20579.	166.00	0.050	0.000	NORM		0.050	0.000	NORM	10.	HEAVY	DARK GRAY/RED	60.80	FAIR
AA	20520.	199.30	0.040	0.010	NORM	NO	0.040	0.100	VSS	30.	HEAVY	NORMAL	64.10	POOR
AA	20584.	201.00	0.040	0.000	NORM	NO	0.100	0.000	NORM	3.	MEDIUM	SLIGHT RED	65.40	POOR
AA	20591.	201.00	0.030	0.010	VSS	NO	0.000	0.000	VSS	8.	HEAVY	NO	66.10	FAIR
AA	20586.	203.00	0.040	0.000	SS	0	0.100	0.020	VSS	15.	LIGHT	SLIGHT BROWN	66.90	FAIR
AA	20576.	204.00	0.050	0.050	SS	180	0.300	0.100	SS	25.	LIGHT	NORM	67.50	POOR

MOTORS IN LOT COMBO: 6 AVG AGE,MO: 195.72 LC AVG SHORE A: 65.13 3 SIGMA-SHORE A: 7.30

LOT COMBO: 29. CTPB MFGR: GTR

AA	STAGE2 SN	MOTOR AGE MO	FWD GAP 0	FWD LIFTING 0	FWD LINER	FWD UNBONDS	AFT GAP 180	AFT LIFTING 180	AFT LINER	AFT VOIDS QUANTITY	AP FWD	DISCOLORATION	SHORE A AVG	MOTOR CONDITION
AA	20557.	166.00	0.010	0.010	VSS		0.020	0.000	SS	24.	LIGHT		64.20	FAIR
AA	20562.	176.00	0.040	0.010	VSS		0.150	0.000	SS	10.	MEDIUM	DARK GRAY/RED	63.33	POOR
AA	20563.	177.00	0.030	0.000	VSS		0.020	0.000	NORM	16.	MEDIUM	DARK GRAY/RED	62.44	FAIR
AA	20558.	181.00	0.030	0.000	NORM	NO	0.050	0.000	VSS	3.	HEAVY	GRAY/RED/BRWN	61.89	FAIR
AA	20569.	190.00	0.050	0.010	SS	NO	0.040	0.000	VSS	15.	MEDIUM	RED/GRAY	63.44	FAIR
AA	20573.	193.00	0.035	0.050	STCKY	YES	0.160	0.040	SS	20.	MEDIUM	NORMAL	61.22	VPOOR
AA	20594.	193.60	0.030	0.020	VSS	NO	0.120	0.060	VSS	10.	MEDIUM	NONE	67.89	FAIR
AA	20575.	199.30	0.040	0.010	VSS	NO	0.100	0.010	VSS	20.	HEAVY	DARK GRAY	68.66	FAIR
AA	20574.	200.40	0.030	0.200	SS	YES	0.100	0.010	SS	10.	HEAVY	NORM	70.66	POOR
AA	20561.	200.80	0.040	0.010	VSS	NO	0.200	0.120	SS	20.	MEDIUM	GRAY	70.22	POOR
AA	20565.	203.00	0.030	0.000	NORM	NO	0.100	0.000	NORM	5.	MEDIUM	NORM	64.00	FAIR
AA	20572.	203.00	0.040	0.020	NORM	YES	0.000	0.000	NORM	12.	LIGHT	NORM	60.30	FAIR
AA	20543.	207.00	0.010	0.000	NORM	NO	0.010	0.000	SS	20.	LIGHT	RED MOTTLE	65.80	FAIR

MOTORS IN LOT COMBO: 13 AVG AGE,MO: 191.55 LC AVG SHORE A: 64.93 3 SIGMA-SHORE A: 10.29

LOT COMBO: 30. CTPB MFGR: PHILLIPS

AA	STAGE2 SN	MOTOR AGE MO	FWD GAP 0	FWD LIFTING 0	FWD LINER	FWD UNBONDS	AFT GAP 180	AFT LIFTING 180	AFT LINER	AFT VOIDS QUANTITY	AP FWD	DISCOLORATION	SHORE A AVG	MOTOR CONDITION
AA	20617.	170.00	0.200	0.000	NORM		0.100	0.000	NORM	4.	VHEAVY	REDDISH	71.80	POOR
AA	20603.	192.00	0.000	0.000	NORM	NO	0.020	0.000	VSS	6.	LIGHT	DARK GRAY	80.00	FAIR
AA	20601.	192.60	0.030	0.000	VSS	NO	0.080	0.050	VSS		VHEAVY	RED	79.89	FAIR
AA	20606.	193.00	0.020	0.010	VSS	NO	0.080	0.000	VSS	3.	MEDIUM	GRAY/RED	78.56	FAIR
AA	20616.	193.60	0.030	0.000	NORM	NO	0.180	0.020	VSS	2.	LIGHT	GRN/GRAY/RED	82.10	POOR
AA	20613.	194.00	0.030	0.000	VSS	NO	0.000	0.000	VSS	3.	VHEAVY	DARK GRAY	81.67	POOR

MOTORS IN LOT COMBO: 6 AVG AGE,MO: 189.20 LC AVG SHORE A: 79.00 3 SIGMA-SHORE A: 11.27

LOT COMBO: 31. CTPB MFGR: GTR

AA	STAGE2 SN	MOTOR AGE MO	FWD GAP 0	FWD LIFTING 0	FWD LINER	FWD UNBONDS	AFT GAP 180	AFT LIFTING 180	AFT LINER	AFT VOIDS QUANTITY	AP FWD	DISCOLORATION	SHORE A AVG	MOTOR CONDITION
AA	20615.	157.00	0.030	0.010	SS	NO	0.030	0.000	NORM		HEAVY	DARK GRAY/RED	64.60	POOR

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AA	STAGE2 SN	MOTOR AGE MO	FWD GAP 0	FWD LIFTING 0	FWD LINER	FWD UNBONDS	AFT GAP 180	AFT LIFTING 180	AFT LINER	AFT VOIDS QUANTI	AP FWD	DISCOLORATION	SHORE A AVG	MOTOR CONDITION
AA	20662.	193.00	0.110	0.050	STCKY	180	0.100	0.070	SS	10.	HEAVY	NORM	63.90	VPOOR

MOTORS IN LOT COMBO: 2 AVG AGE,MO: 175.00 LC AVG SHORE A: 64.25 3 SIGMA-SHORE A: 1.48

LOT COMBO: 32. CTPB MFGR: PHILLIPS

AA	STAGE2 SN	MOTOR AGE MO	FWD GAP 0	FWD LIFTING 0	FWD LINER	FWD UNBONDS	AFT GAP 180	AFT LIFTING 180	AFT LINER	AFT VOIDS QUANTI	AP FWD	DISCOLORATION	SHORE A AVG	MOTOR CONDITION
AA	20635.	156.00	0.000	0.000	NORM		0.000	0.010	NORM	2.	VHEAVY	REDDISH	72.44	FAIR
AA	20626.	160.00	0.000	0.000	NORM		0.010	0.000	NORM		HEAVY	DARK GRAY/RED	69.80	FAIR
AA	20646.	190.70	0.020	0.000	VSS	NO	0.000	0.000	NORM	10.	LIGHT	RED STREAKS	77.67	FAIR
AA	20633.	192.30	0.030	0.000	NORM	NO	0.000	0.000	VSS	1.	MEDIUM	REDDISH	73.67	POOR
AA	20657.	194.00	0.030	0.000	NORM	NO	0.020	0.000	NORM	5.	NONE	REDISH-GREY	71.00	FAIR
AA	20629.	197.00	0.060	0.000	STCKY	N	0.100	0.010	SS	10.	HEAVY	BRN MOTTLING	72.40	VPOOR
AA	20631.	210.00	0.040	0.000	NORM	O	0.150	0.030	SS	2.	HEAVY	REDDISH	70.50	POOR

MOTORS IN LOT COMBO: 7 AVG AGE,MO: 185.71 LC AVG SHORE A: 72.50 3 SIGMA-SHORE A: 7.90

LOT COMBO: 33. CTPB MFGR: GTR

AA	STAGE2 SN	MOTOR AGE MO	FWD GAP 0	FWD LIFTING 0	FWD LINER	FWD UNBONDS	AFT GAP 180	AFT LIFTING 180	AFT LINER	AFT VOIDS QUANTI	AP FWD	DISCOLORATION	SHORE A AVG	MOTOR CONDITION
AA	20647.	160.00	0.010	0.000	VSS		0.030	0.000	NORM	20.	HEAVY	REDDISH	55.20	POOR
AA	20637.	163.00	0.030	0.000	NORM		0.030	0.000	VSS	10.	VHEAVY	REDDISH	59.60	POOR
AA	20666.	172.00	0.040	0.000	NORM		0.050	0.000	NORM	20.	MEDIUM	DARK GRAY/RED	62.11	FAIR
AA	20672.	173.00	0.000	0.000	NORM	NO	0.000	0.000	NORM	20.	HEAVY	DARK GRAY/RED	68.50	FAIR
AA	20668.	178.00	0.030	0.000	VSS	NO	0.080	0.000	VSS	20.	MEDIUM	NONE	61.67	FAIR
AA	20636.	184.00	0.020	0.010	VSS	NO	0.100	0.020	VSS	20.	VHEAVY	DARK GRAY/RED	65.66	POOR
AA	20638.	189.00	0.030	0.010	VSS	NO	0.200	0.100	VSS	6.	VHEAVY	GRAY/RED	69.89	FAIR

MOTORS IN LOT COMBO: 7 AVG AGE,MO: 174.14 LC AVG SHORE A: 63.23 3 SIGMA-SHORE A: 15.46

LOT COMBO: 34. CTPB MFGR: GTR

AA	STAGE2 SN	MOTOR AGE MO	FWD GAP 0	FWD LIFTING 0	FWD LINER	FWD UNBONDS	AFT GAP 180	AFT LIFTING 180	AFT LINER	AFT VOIDS QUANTI	AP FWD	DISCOLORATION	SHORE A AVG	MOTOR CONDITION
AA	20710.	185.80	0.060	0.020	VSS	NO	0.040	0.000	VSS	40.	MEDIUM	REDDISH	64.99	FAIR
AA	20706.	187.00	0.040	0.000	SS	O	0.000	0.000	VSS	20.	LIGHT	NORM	65.60	FAIR

MOTORS IN LOT COMBO: 2 AVG AGE,MO: 186.40 LC AVG SHORE A: 65.30 3 SIGMA-SHORE A: 1.29

LOT COMBO: 36. CTPB MFGR: GTR

AA	STAGE2 SN	MOTOR AGE MO	FWD GAP 0	FWD LIFTING 0	FWD LINER	FWD UNBONDS	AFT GAP 180	AFT LIFTING 180	AFT LINER	AFT VOIDS QUANTI	AP FWD	DISCOLORATION	SHORE A AVG	MOTOR CONDITION
AA	20725.	183.70	0.040	0.000	NORM	NO	0.000	0.000	NORM	15.	HEAVY	DARK GRAY	67.66	FAIR
AA	20717.	188.00	0.020	0.000	SS	O	0.050	0.000	SS	40.	LIGHT	NORM	69.00	FAIR

MOTORS IN LOT COMBO: 2 AVG AGE,MO: 185.85 LC AVG SHORE A: 68.33 3 SIGMA-SHORE A: 2.84

LOT COMBO: 37. CTPB MFGR: GTR

AA	STAGE2 SN	MOTOR AGE MO	FWD GAP 0	FWD LIFTING 0	FWD LINER	FWD UNBONDS	AFT GAP 180	AFT LIFTING 180	AFT LINER	AFT VOIDS QUANTI	AP FWD	DISCOLORATION	SHORE A AVG	MOTOR CONDITION
AA	20746.	181.50	0.020	0.000	NORM	O	0.000	0.000	NORM	4.	NONE	REDDISH	70.44	FAIR

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AA	STAGE2 SN	MOTOR AGE MO	FWD GAP 0	FWD LIFTING 0	FWD LINER	FWD UNBONDS	AFT GAP 180	AFT LIFTING 180	AFT LINER	AFT VOIDS QUANTITY	AP FWD	DISCOLORATION	SHORE A AVG	MOTOR CONDITION
# MOTORS IN LOT COMBO: 1 AVG AGE,MO: 181.50 LC AVG SHORE A: 70.44 3 SIGMA-SHORE A:														
LOT COMBO: 41. CTPB MFGR: PHILLIPS														
AA	20808.	177.00	0.000	0.000	NORM	0	0.000	0.000	NORM	5.	NONE	REDDISH-GREY	80.50	POOR
# MOTORS IN LOT COMBO: 1 AVG AGE,MO: 177.00 LC AVG SHORE A: 80.50 3 SIGMA-SHORE A:														
LOT COMBO: 42. CTPB MFGR: GTR														
AA	20874.	159.50	0.030	0.020	VSS	NO	0.020	0.000	NORM	2.	HEAVY	GRAY\	64.67	POOR
# MOTORS IN LOT COMBO: 1 AVG AGE,MO: 159.50 LC AVG SHORE A: 64.67 3 SIGMA-SHORE A:														
LOT COMBO: 52. CTPB MFGR: GTR														
AA	21049.	140.00	0.080	0.010	VSS	NO	0.180	0.120	SS	15.	NONE	GRAY	66.55	POOR
# MOTORS IN LOT COMBO: 1 AVG AGE,MO: 140.00 LC AVG SHORE A: 66.55 3 SIGMA-SHORE A:														
LOT COMBO: 60. CTPB MFGR: GTR														
AA	21321.	122.00	0.120	0.040	VS	YES	0.220	0.100	VS	2.	MEDIUM	DARK GRAY	63.22	VPOOR
# MOTORS IN LOT COMBO: 1 AVG AGE,MO: 122.00 LC AVG SHORE A: 63.22 3 SIGMA-SHORE A:														
LOT COMBO: 67. CTPB MFGR: PHILLIPS														
AA	21480.	111.00	0.000	0.000	NORM	NO	0.000	0.000	NORM	4.	NONE	NONE	74.20	FAIR
# MOTORS IN LOT COMBO: 1 AVG AGE,MO: 111.00 LC AVG SHORE A: 74.20 3 SIGMA-SHORE A:														

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AA	STAGE2 SN	MOTOR AGE MO	FWD GAP 0	FWD LIFTING 0	FWD LINER	FWD UNBONDS	AFT GAP 180	AFT LIFTING 180	AFT LINER	AFT VOIDS QUANTITY	AP FWD	DISCOLORATION	SHORE A AVG	MOTOR CONDITION

****

		PHILLIPS MOTORS	GTR MOTORS
COUNT		98	121
MOTOR CONDITION:	FAIR	43	62
	POOR	42	37
	VPOOR	13	22

Figure A-16. Washout Motor Visual Inspection Report, Sheet 10 of 10

RECORD	MOTOR_SN	CORE_STRP	LINE_LOT	LOT_COMB	CTBP	INSP_DATE	REMARKS
7	AA 20736	03/26/70		37	6	10/31/84	Normal
8	AA 20805	10/29/70		41	P	11/02/84	No debond
13	AA 21591	02/25/78	Cv	72		01/18/85	No debond
14	AA 21579	10/16/77	Cv	72		01/29/85	No significant debond
15	AA 21584	11/19/77	Cv	71		03/05/85	No debond
4	AA 20993	04/02/72	Kt	49	6	09/24/84	No debond
1	AA 21049	10/07/72	Lf	52	6	10/23/83	Excised & tested @ ASPC
6	AA 21058	10/25/72	Lf	53	6	10/11/84	Liner flowing. 1/32" debond 60 to 120 deg.
10	AA 21046	10/01/72	Lf	52	6	11/28/84	.090" gap full 360 deg.
11	AA 21117	03/11/73	Lf	55	6	12/11/84	Max gap .043" ~3/64" normal degradation
5	AA 21159	07/14/73	Mk	54	P	10/04/84	No debond
2	AA 21270	04/07/74	Ro	59	6	08/10/84	No debond
3	AA 21321	07/10/74	Sq	60	6	09/06/84	Liner flowing. Excised/tested
9	AA 21352	09/17/74	Sq	62	P	11/13/84	Tacky but normal
33	AA 21419	08/16/75	Vr	64		/ /	
34	AA 21410	07/12/75	Vr	65		/ /	
35	AA 21413	07/19/75	Vr	64		/ /	
16	AA 21506	10/03/76	Zs	68		03/07/85	No debond
17	AA 21510	11/01/76	Zs	68		03/07/85	No debond
18	AA 21505	10/02/76	Zs	68		03/13/85	Nodebond
19	AA21521	01/22/77	Zs	70		03/13/85	No debond
20	AA21513	11/27/76	Zs	68		03/15/85	3/64" sep. @ 170, 1/32" @ 190 deg.
21	AA 21522	01/29/77	Zs	69		03/19/85	Hairline sep. @ ~ 210 deg.
22	AA 21508	10/10/76	Zs	68		04/04/85	Mfg. anomally @ign. boot-prop. interface 60 to 120 deg
23	AA 21482	05/17/76	Zs	67		04/08/85	No debond
24	AA 21503	09/26/76	Zs	68		04/10/85	No debond
25	AA 21512	11/14/76	Zs	68		04/11/85	No debond
26	AA 21509	10/16/76	Zs	68		05/02/85	No debond
27	AA 21507	10/09/76	Zs	68		05/15/85	No debond
29	AA 21504	09/29/76	Zs	68		/ /	
30	AA 21472	02/24/76	Zs	67		/ /	
31	AA 21460	01/19/76	Zs	66		/ /	
36	AA 21465	02/01/76	Zs	67		/ /	
12	AA 21434	09/28/75	Zs*	64		01/10/85	,Tacky liner. Excessive gap 1/8" to 3/16"
28	AA 21436	10/08/75	Zs*	64		07/29/85	,Dark color tacky liner. ~1/16" sep. full 360 deg.
32	AA 21423	08/30/75	Zs*	64		/ /	,May be liner lot Vr
37	AA 21427	09/08/75	Zs*	64		08/06/85	,Debond < 1/32" top half boot,liner dark & flowing

Figure A-17. Visual Inspection Data from OO-ALC

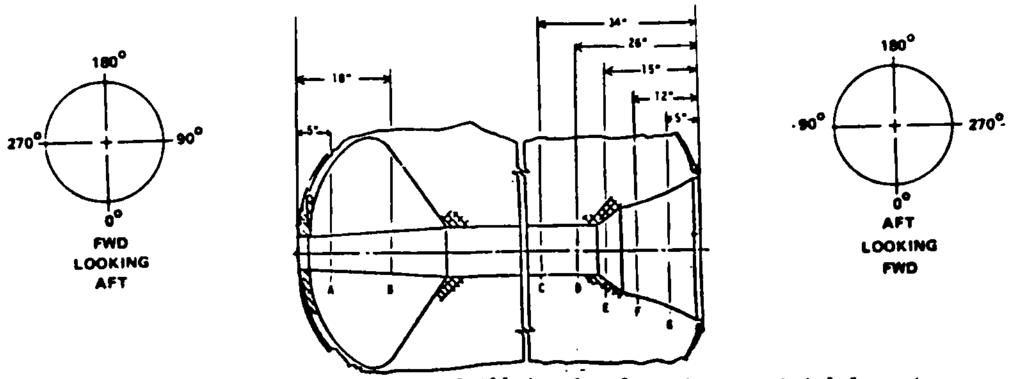
Motor Characteristics	Visual Inspection Ranking Criteria		
Main Criteria	**Very Poor**	**Poor**	**Fair**
Forward Nipple Gap	≥ 0.06	≥ 0.03	≤ 0.03
Lifting	≥ 0.04	≥ 0.03	≤ 0.03
Aft Nipple Gap	≥ 0.10	≥ 0.05	≤ 0.05
Lifting	≥ 0.10	≥ 0.03	≤ 0.03
Nipple Bonding	Unbounded 180° to 270° in length	45° to 90° in Length	None
Liner Quality	Sticky	Very Slightly Sticky or Slightly Sticky	Very Slightly Sticky or Normal
Cracks	Any Observed	None	None
Secondary Criteria			
Slump	> 0.25 in.	0.25 in.	≤ 0.25 in.
Voids			
Quantity	> 20	10 to 20	< 10
Size	> 0.3 in.	0.1 to 0.3 in.	0.1 to 0.2 in.
Ammonium Perchlorate	Heavy to Medium	Light to Medium	None to Light
Shore "A" Hardness	≤55 or ≥78	≤63 or ≥73	63 to 73
Discoloration	Dark Gray/Red	Dark Gray/Red	None
Other Criteria (Tertiary)			
Rough Propellant Surface	Very Rough	Somewhat Rough	Normal
SD 844 Running on Propellant Grain	Any Observed	Any Observed	None

These criteria are not to be taken as absolute factors for determining motor condition. In general, if a motor meets 75% of the values in any one column, that column is its classification. Additionally, the table is weighted such that primary consideration is given to the main criteria. Secondary and tertiary criteria are used primarily when motors are borderline in caregory.

Figure A-18. Visual Inspection Ranking Criteria

Motor SN: AA 20596 Cast Date: 25 September 1968 CTPB Vendor: GTR

Test Date: 24 October 1984 Bay Temp: 72°F Age at Test: 193 (Mos)



Average of All Angular Locations at Axial Location:

	A	B	C	D	E	F	G
Shore A2	50	50.25	60.5	63	66.5	65.8	67.3
On-Surface (K_{77})	N/A	36.1	48.4	47.6	46.17	38.7	41.6
- E_o (psi)	N/A	940	1310	1285	1241	1015	1102
- σ_m (psi)	N/A	97	107.8	107.1	105.8	99.3	101.8
- ε_m (%)	N/A	18.2	15.1	15.3	15.6	17.7	16.9
- ε_b (%)	N/A	26.0	20.6	20.9	21.5	24.7	23.4
Temperature (°F)	N/A	72.3	78.5	81.8	79	76.5	76.5

Visual Observations

1. Forward Bondline — Boot separation 0.05" at 150°.

2. Aft Bondline — Boot separation of 0.10" entire circumference as evidenced by concentric depression in the SD 844-1 end restriction.

3. Forward Bore — Scratches to 0.25" wide entire length of fin rays. Scratches and scuffing caused by installing and removing igniter assembly. Release agent on surface and in slots.

4. Cylindrical Bore — Large scrap of release agent at 180°. Large patch 6 x 12" of surface polymer appears to be peeled away at the bore-fin ray interface. 270° - 230°.

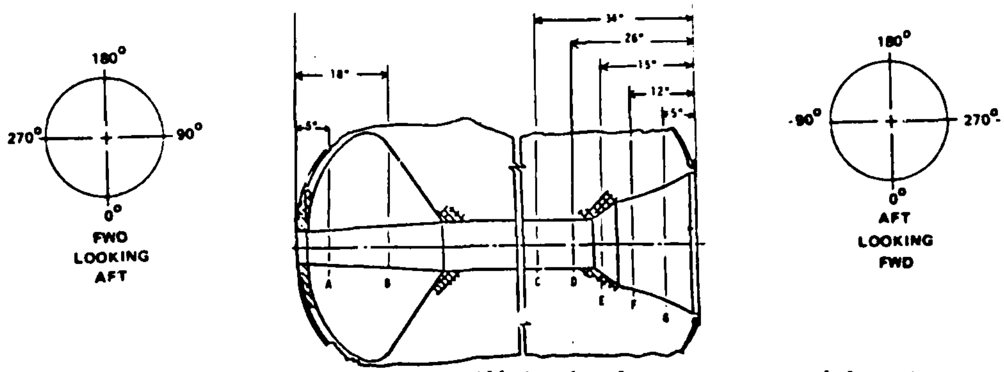
5. Aft Nozzle Well — Voids: 40°, 2" in x 0.25"; 60°, 4" in x 0.25"; 75°, 0.25" in x 0.25"; 130°, 4" in x 0.25", 8" in x 0.25"; 200°, 8" in x 0.12"; 220°, 2" in x 0.25"; 195°, 2" in x 0.25".

6. Other — SD 844-1 end restriction is tacky. Profusion of crystals on bore surface and in fin slots. Crystals removed at NDT test locations to facilitate "On-Surface" testing.

Figure A-19. Summary of On-Surface Tests Conducted on Minuteman Stage II Motors, Sheet 1 of 13

Motor SN: R6-049 Cast Date: 5 November 1984 CTPB Vendor: Phillips

Test Date: 3 December 1984 Bay Temp: 78°F Age at Test: 1 (Mos)



Average of All Angular Locations at Axial Location:

	A	B	C	D	E	F	G
Shore A2	47.5	55.5	64.8	63	65.8	66	66
On-Surface (K_{77})	27.42	29.11	34.66	36.83	28.9	26.68	28.91
- E_o (psi)	699.05	744.75	899.19	961.39	739.04	679.23	739.04
- σ_m (psi)	89.48	90.6	95.79	97.68	90.77	88.84	90.77
- ε_m (%)	21.82	21.11	19.04	18.32	21.2	22.12	21.19
- ε_b (%)	31.05	29.95	26.73	25.61	30.08	31.55	30.08
Temperature (°F)	68.8	68.0	65.5	66.8	65	63.8	63.00

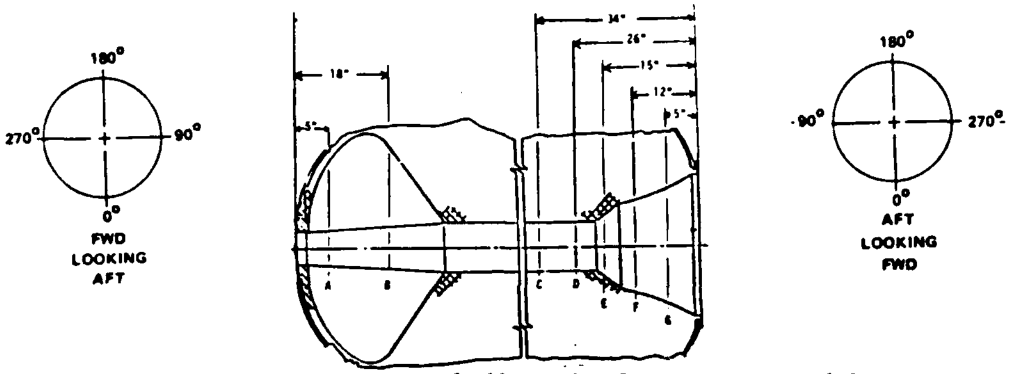
Visual Observations

1. Forward Bondline N/A
2. Aft Bondline N/A
3. Forward Bore Scratches 1" to 6" long in all fin rays. Black substance in bottom of 0° fin slot. 1" x 1/2" piece of styrofoam in bottom of 110° fin slot.
4. Cylindrical Bore N/A
5. Aft Nozzle Well Voids: 3/4" dia x 3/8" deep 5" in, 1/2" dia x 3/16" deep 6" in at 225°.
6. Other N/A

Figure A-19. Summary of On-Surface Tests Conducted on Minuteman Stage II Motors, Sheet 2 of 13

Motor SN: PQA 6-107 (R6-051) Cast Date: 19 November 1984 CTPB Vendor: Phillips

Test Date: 14 December 1984 Bay Temp: 70°F Age at Test: 1 (Mos)



	Average of All Angular Locations at Axial Location:						
	A	B	C	D	E	F	G
Shore A2	53.5	59	65.3	65.8	66.8	67	66.8
On-Surface (K_{77})	30.55	33.66	39.57	39.37	33.73	31.44	30.65
- E_o (psi)	784.2	870.87	1041.38	1035.49	872.85	808.78	786.94
- σ_m (psi)	92.21	94.9	100.06	99.89	94.98	92.98	92.3
- ϵ_m (%)	20.54	19.39	17.47	17.53	19.36	20.2	20.5
- ϵ_b (%)	29.06	27.27	24.29	24.39	27.23	28.53	29.0
Temperature (°F)	67	68.3	70.5	69.8	68.0	68.3	67.3

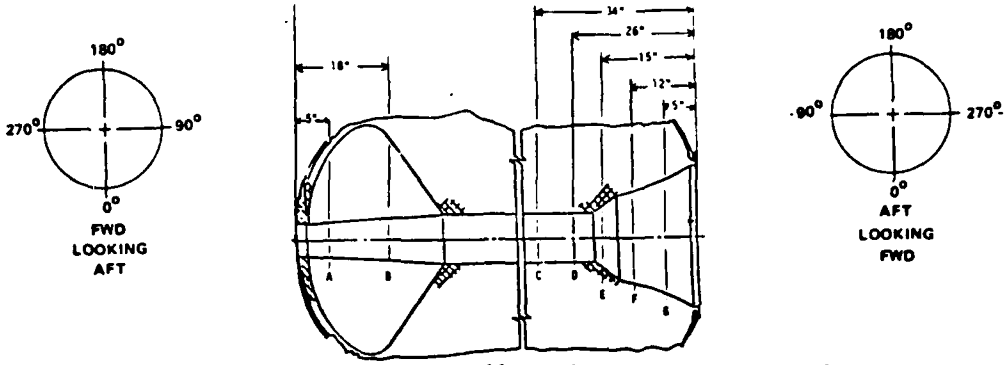
Visual Observations

1. Forward Bondline N/A
2. Aft Bondline N/A
3. Forward Bore Minor longitudinal scratches in fin rays. Portions of fin slot area surface are rough, possibly caused by nonuniform application of release agent to fins.
4. Cylindrical Bore N/A
5. Aft Nozzle Well Void 1/2" x 1/2" 90°, 8" in; bump 1/2" x 3/16", 60° 18" in.
6. Other 3/4" x 1/2" fin material in bottom of 180° and 310° fin slots. Propellant surface is tacky.

Figure A-19. Summary of On-Surface Tests Conducted on Minuteman Stage II Motors, Sheet 3 of 13

Motor SN: AA 20613 Cast Date: 27 November 1968 CTPB Vendor: Phillips

Test Date: 25 January 1985 Bay Temp: 70°F Age at Test: 208 (Mos)



Average of All Angular Locations at Axial Location:

	A	B	C	D	E	F	G
Shore A2	62	69.5	75.7	78	78	79.8	78.5
On-Surface (K_{77})	55.25	55.43	57.7	62.8	66.1	62.6	56.9
- E_o (psi)	1530.4	1536.3	1611.6	1785	1900	1778	1585
- σ_m (psi)	113.7	113.9	115.8	120.3	123.2	120.1	115.2
- ϵ_m (%)	13.5	13.5	13.0	12.0	11.4	12.0	13.2
- ϵ_b (%)	18.1	18.1	17.4	15.8	14.8	15.9	17.6
Temperature (°F)	63	63	66.5	67.5	66.8	66.5	66.3

Visual Observations

1. Forward Bondline: Boot separation 0.025" at 0° - 45°. Boot lifting 0.015" at 35°.

2. Aft Bondline: Boot separation 0.1" at 0°. SD 844-1 end restriction is tacky.

3. Forward Bore: Longitudinal surface scratches on fin rays due to igniter installation and removal. Propellant slump of 1/4" at forward boot nipple.

4. Cylindrical Bore: 2" x 2" portion of propellant surface is missing at fin ray cylinder bore interface at 90°.

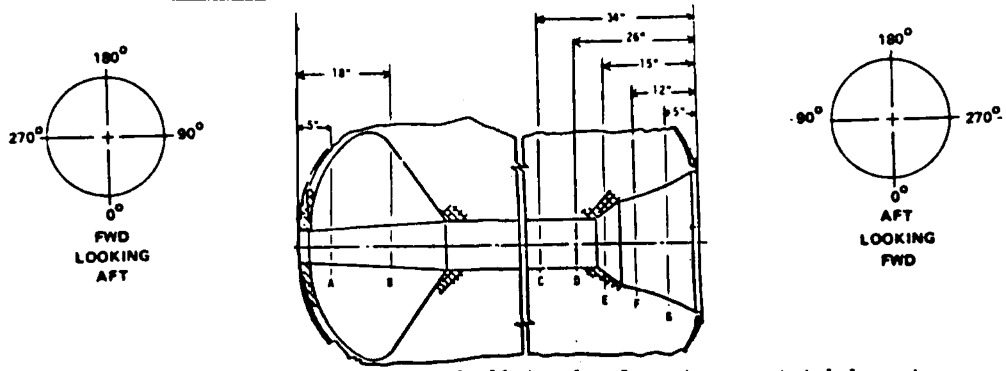
5. Aft Nozzle Well: Void 3/8" dia. 1" in at 50°. 1/2" dia. 7" in at 270°.

6. Other: Brown discoloration of propellant surface. Entire propellant surface area covered with oxidizer crystals.

Figure A-19. Summary of On-Surface Tests Conducted on Minuteman Stage II Motors, Sheet 4 of 13

Motor SN: AA 20530 Cast Date: March 1968 CTPB Vendor: GTR

Test Date: 21 February 1985 Bay Temp: 75°F Age at Test: 203 (Mos)



Average of All Angular Locations at Axial Location:

	A	B	C	D	E	F	G
Shore A2	54.5	57.8	63.8	66	69.5	70	68.5
On-Surface (K_{77})	34.8	34.6	40.9	44.9	45.0	45.3	37.7
- E_o (psi)	903.2	897.5	1080.8	1201.6	1204.7	1213.9	986.6
- σ_m (psi)	95.9	95.7	101.2	104.7	104.8	105.1	98.4
- ϵ_m (%)	19.1	19.1	17.1	16.0	15.9	15.9	18.0
- ϵ_b (%)	26.7	26.8	23.7	22.0	21.9	21.8	25.2
Temperature (°F)	71.3	69.3	72.5	72	71	71.5	70.8

Visual Observations

1. Forward Bondline N/A

2. Aft Bondline Boot separation 0°, 1/8", 90°, 3/32", 180°, 5/32", 270°, 1/8". Cut in insulation at boss interface at 165°. SD 844-1 end restriction is soft and tacky.

3. Forward Bore Void 1" dia. on fin ray at 250°. Longitudinal scratches on all fin rays. Release agent on 350° fin ray. Propellant slump 1/4" . Propellant scrap at 135°.

4. Cylindrical Bore Abrasion 3" x 4" at 120° fin ray bore interface. Slight brown mottling, few scratches.

5. Aft Nozzle Well Voids: 3/16" x 3/16" deep at 260°. Few propellant scraps. Light dusting of oxidizer crystals.

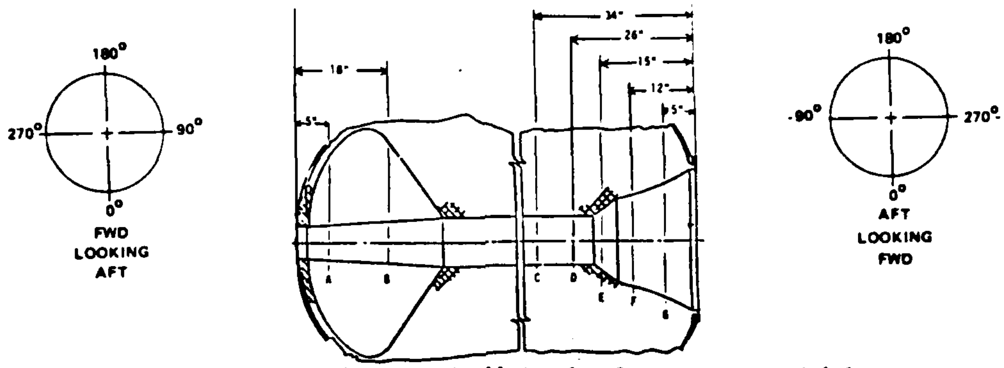
6. Other N/A

Figure A-19. Summary of On-Surface Tests Conducted on Minuteman Stage II Motors, Sheet 5 of 13

Report 0162-06-SAAS-35, Appendix A

Motor SN: AA 20402 Cast Date: 8 February 1967 CTPB Vendor: GTR

Test Date: 1 April 1985 Bay Temp: 65°F Age at Test: 217 (Mos)



Average of All Angular Locations at Axial Location:

	A	B	C	D	E	F	G
Shore A2	56.3	61.8	67.8	69.5	72.3	70.8	70
On-Surface (K_{77})	45.3	42.1	49.9	48.4	52.8	47	41.9
- E_o (psi)	1213.9	1116.7	1357.6	1310.2	1450.5	1266.5	1110.2
- σ_m (psi)	105.1	102.3	109.1	107.8	111.6	106.5	102.1
- ϵ_m (%)	15.9	16.7	14.7	14.1	14.0	15.4	16.8
- ϵ_b (%)	21.8	23.2	20.0	20.6	19.0	21.1	23.2
Temperature (°F)	69.3	72.5	72.8	72.8	69.0	68	68

Visual Observations

1. Forward Bondline: Boot separation 3/32" entire circumference. Boot lifting 1/8" at 220°. Boot unbonded from 180° to 270°. Boot shrinkage from 180° to 270°.

2. Aft Bondline: End restriction separation and lifting 1/8" entire circumference. SD 844-1 is sticky.

3. Forward Bore: Crack 1-3/8" long x 3/32" at 90° fin ray. Propellant slump 1/8". Light dust of oxidizer crystals. Fin material residue 1/4" bottom of 0° fin slot.

4. Cylindrical Bore: Light dusting of oxidizer crystals.

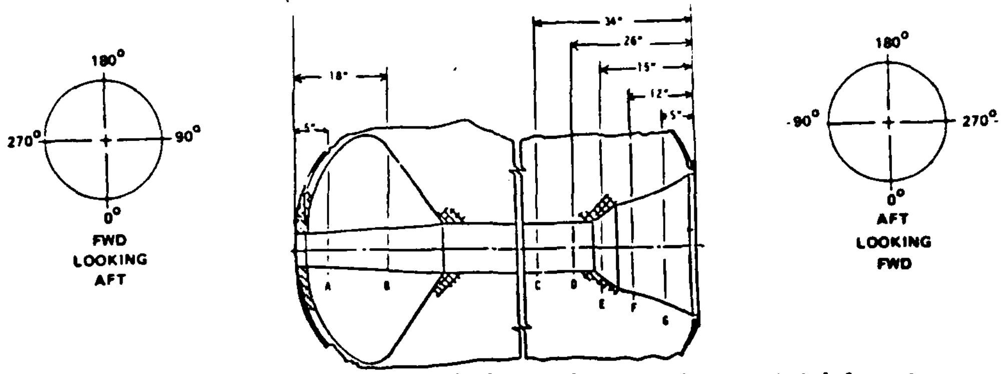
5. Aft Nozzle Well: Voids: 0°, 1/8", 14" in; 55°, 3/16", 15" in; 50°, 3/32", 3" in; 90°, 1/4", 4" in; 180°, 3/8", 18" in; 210°, 1/8", 18" in; 270°, 1/8", 17" in; 290°, 3/16", 6" in.

6. Other: Epoxy repair of aft case insulation at boss 1" x 1/4" at 10° and 280°.

Figure A-19. Summary of On-Surface Tests Conducted on Minuteman Stage II Motors, Sheet 6 of 13

Motor SN: R6-072 Cast Date: 11 March 1985 CTPB Vendor: Phillips

Test Date: 12 April 1985 Bay Temp: 72°F Age at Test: 1 (Mos)



Average of All Angular Locations at Axial Location:

	A	B	C	D	E	F	G
Shore A2	51.0	57.0	63.0	63.0	64.0	63.0	66.0
On-Surface (K_{77})	31.8	35.4	44.0	35.8	30.3	30.3	31.8
- E_o (psi)	818.8	920.3	1174.0	931.7	733.3	733.3	818.8
- σ_m (psi)	93.3	96.4	103.9	96.8	92.0	92.0	93.3
- ϵ_m (%)	20.0	18.8	16.2	18.6	20.6	20.6	20.0
- ϵ_b (%)	28.3	26.3	22.3	26.1	29.2	29.2	28.3
Temperature (°F)	69.3	70.5	71.8	70.8	70.8	71.0	70.8

Visual Observations

1. Forward Bondline — No forward bond discrepancies.

2. Aft Bondline — No aft bond discrepancies.

3. Forward Bore — Small fin material residue in apex of all fin slots except 180°. Rough surface in fin slots due to poor release of fin material.

4. Cylindrical Bore — Few minor longitudinal scratches.

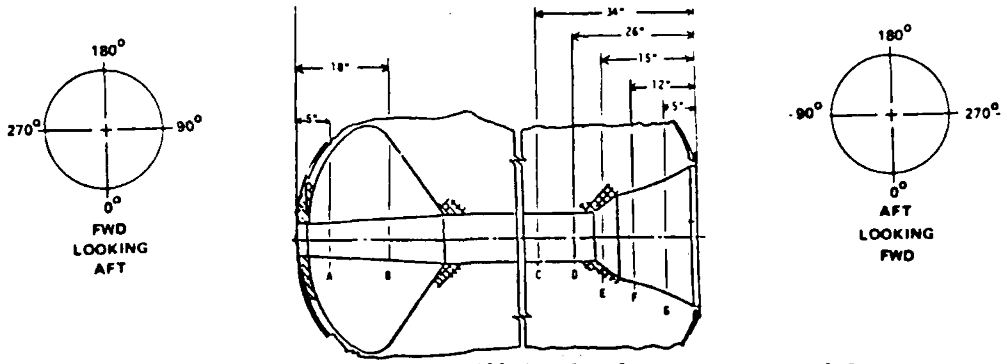
5. Aft Nozzle Well — Voids: 30°, 3/16" 6" in; 85°, 1/8", 6" in; 90°, 3/8", 6" in; 200°, 3/16", 7" in; 230°, 1/8", 1" in; 270°, 1/8", 3" in; 275°, 1/8", 6" in; 350°, 1/8", 6" in.

6. Other — N/A

Figure A-19. Summary of On-Surface Tests Conducted on Minuteman Stage II Motors, Sheet 7 of 13

Motor SN: AA 20629 | Cast Date: 15 January 1969 | CTPB Vendor: Phillips

Test Date: 3 May 1985 | Bay Temp: 75°F | Age at Test: 197 Mos



Average of All Angular Locations at Axial Location:

	A	B	C	D	E	F	G
Shore A2	55.8	62.8	71.3	72.3	77	74.8	75
On-Surface (K_{77})	43.4	48.2	49.0	52.0	56.9	53.3	51.3
- E_o (psi)	1156	1304	1329	1424.7	1585	1467	1402
- σ_m (psi)	103.4	107.6	108.3	110.9	115.2	112	110.3
- ϵ_m (%)	16.4	15.1	14.9	14.2	13.2	13.9	14.4
- ϵ_b (%)	22.6	20.7	20.4	19.3	17.6	18.8	19.5
Temperature (°F)	77.7	79	78	79	79	79	78.5

isual Observations

1. Forward Bondline — Boot separation 1/32" at 90°, 1/16" at 150°, 1/32" at 210°, 1/32" at 270°. Boot lifting 1/64" at 90°, 1/16" at 150°, 1/32" at 210°. Degraded liner at boot termination 150°, 270°.

2. Aft Bondline — Aft boot separation 3/32" at 160°, 1/8" at 0°. SD 844-1 cracked and separated at 160°.

3. Forward Bore — Propellant overcast on boot 90° - 290°, RTV at 0°, gouge in fin slot at 110° Cut in fin ray at 130° and 300°. Slump 1/4".

4. Cylindrical Bore — Oxidizer crystals on surface, longitudinal scratches.

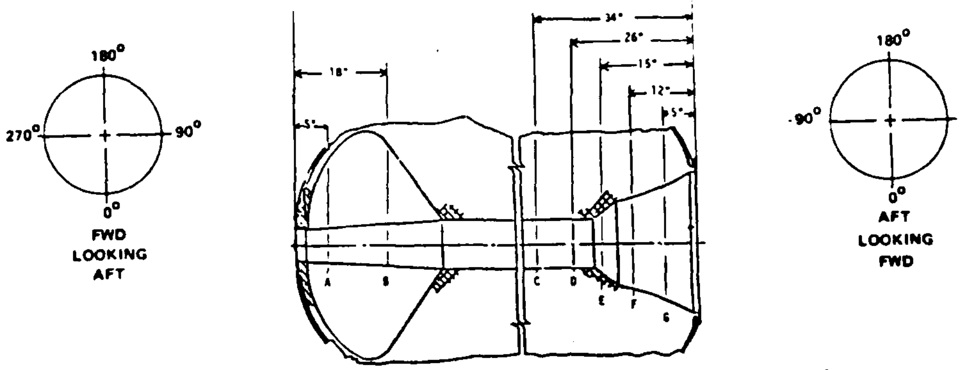
5. Aft Nozzle Well — Crack in propellant grain at 270° 16" from aft boss. Crack length 11", width 0.005" to 1/16", nominal depth 3/8". Void at 260° 1/4 dia. 1" from aft boss. Scratch 6" long x 1/4" wide at 90°.

6. Other — Propellant discoloration brown mottling. Aft nozzle well abraded at 270°. Portions of polymer surface missing.

Figure A-19. Summary of On-Surface Tests Conducted on Minuteman Stage II Motors, Sheet 8 of 13

Motor SN: PQA 6-108 (R6-069) Cast Date: 19 March 1985 CTPB Vendor: Phillips

Test Date: 11 June 1985 Bay Temp: 92°F Age at Test: 2-3/4 (Yrs)



	Average of All Angular Locations at Axial Location:						
	A	B	C	D	E	F	G
Shore A2	48.8	55.5	61.3	64.3	67.0	66.5	66
On-Surface (K_{77})	37.9	40.3	43.6	45.9	42.3	41.1	43.1
- E_o (psi)	992.4	1063	1162	1232.4	1122.7	1086.8	1146.8
- σ_m (psi)	98.6	100.7	103.6	105.6	102.4	101.4	103.1
- ϵ_m (%)	18.0	17.3	16.3	15.7	16.7	17.0	16.5
- ϵ_b (%)	25.1	24.0	22.5	21.6	23.1	23.6	22.7
Temperature (°F)	88	88	90.3	89.8	90.5	91	91

Visual Observations

1. Forward Bondline: No discrepancies.

2. Aft Bondline: Small cut in aft boot at 90° and 270°. Case insulation void 1/32" wide x 1/2" at 270°.

3. Forward Bore: Propellant slump 1/4". Four 0.1" voids on 130° fin ray 7.5" to 10" from boss - few longitudinal scratches in fins.

4. Cylindrical Bore: Few longitudinal scratches in bore.

5. Aft Nozzle Well: Voids: 0.3", 5-1/2" in at 195°; 0.15", 6-1/2" in at 200°, 0.3", 6" in at 10° 0.1", 9" in at 140°.

6. Other: Rough surface patches in all fin slots due to portions of polymer surface missing.

Figure A-19. Summary of On-Surface Tests Conducted on Minuteman Stage II Motors, Sheet 9 of 13

AD-A162 884   AGING AND SURVEILLANCE PROGRAM MINUTEMAN II/III STAGE   3/3
II PROGRAM PROGRESS(U) AEROJET STRATEGIC PROPULSION CO
SACRAMENTO CA NOV 85 ASPC-0162-06-SAAS-35

UNCLASSIFIED   F42600-84-D-1275   F/G 21/8.2   NL

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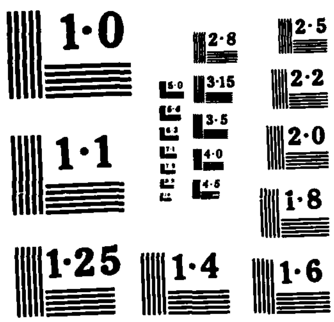
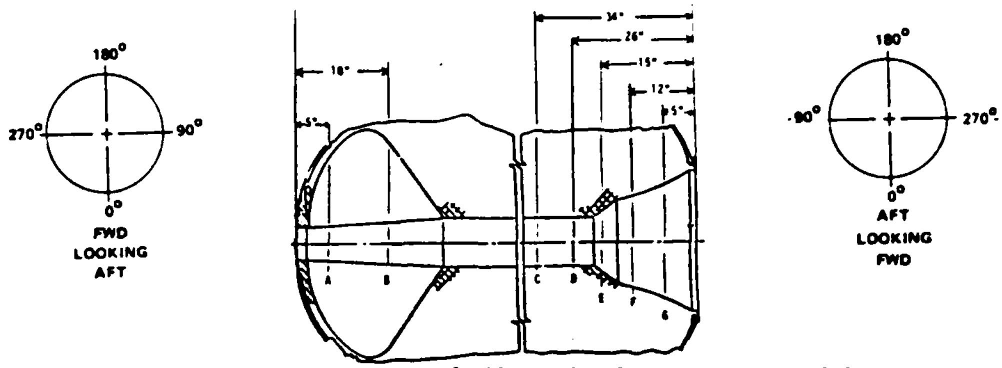


NATIONAL BUREAU OF STANDARDS
MICROCOPY RESOLUTION TEST CHART

Motor SN: 1976A Plug Motor Cast Date: 22 April 1976 CTPB Vendor: Phillips

Test Date: 24 June 1985 Bay Temp: 91°F Age at Test: 110 Mos



Average of All Angular Locations at Axial Location:

	A	B	C	D	E	F	G
Shore A2	53.5	63.8	71.5	70.8	72.8	73.8	73.3
On-Surface (K_{77})	50.9	55.4	61.5	62.9	63.9	58.4	55.2
- E_o (psi)	1389.4	1535.4	1740.2	1788.3	1823.0	1635.0	1528.0
- σ_m (psi)	109.9	113.9	119.2	120.4	121.3	116.5	113.7
- ϵ_m (%)	14.5	13.5	12.2	12.0	11.8	12.9	13.5
- ϵ_b (%)	19.7	18.2	16.2	15.8	15.5	17.1	18.2
Temperature (°F)	83	83	80.5	82	83	83	83

Visual Observations

1. Forward Bondline — Forward boot nipple is abraded due to removal of excess liner material.

2. Aft Bondline — End restriction material SD 844-1 is degraded, sticky and tacky. Restriction material has run five inches into the aft nozzle area from 90° to 270°.

3. Forward Bore — Small fin material residue in fin rays at 0°, 180°, 290°. Slump 1/8". Scratch on 310° fin ray 2" x 3/16".

4. Cylindrical Bore — Light dusting of AP crystals. Few small scraps of propellant.

5. Aft Nozzle Well — Voids: 10°, 1/8", 5" in; 190°, 3/32", 7" in; 230°, 1/8", 6-1/2" in; 270°, 1/8", 6-1/2" in. Scratch at 270° 4" x 1/8". Light brown discoloration of propellant.

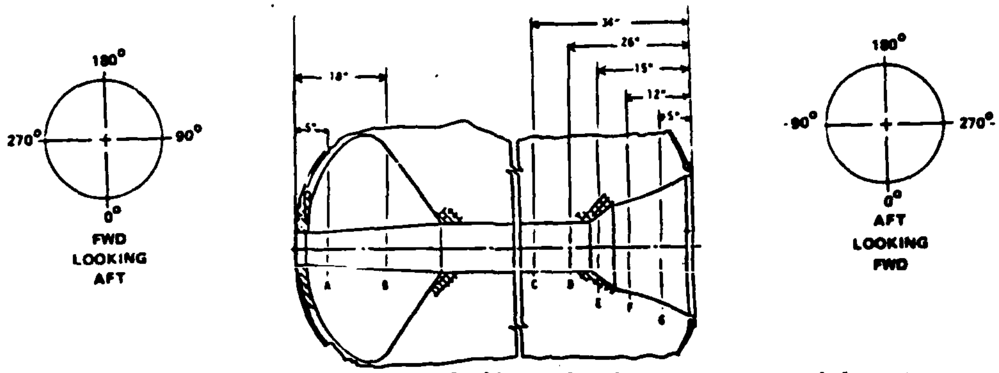
6. Other

Figure A-19. Summary of On-Surface Tests Conducted on Minuteman Stage II Motors, Sheet 10 of 13

Report 0162-06-SAAS-35, Appendix A

Motor SN: AA 21321 Cast Date: 28 June 1974 CTPB Vendor: GTR

Test Date: 3 July 1985 Bay Temp: 92° F Age at Test: 132 (Mos)



Average of All Angular Locations at Axial Location:

	A	B	C	D	E	F	G
Shore A2	45.5	50.0	52.5	52.8	57.8	57.8	58.3
On-Surface (K_{77})	25.6	27.9	26.6	30.3	29.5	27.2	27.2
- E_o (psi)	650.5	712.0	677.1	777.3	755.4	693.1	693.1
- σ_m (psi)	87.9	89.9	88.8	92.0	91.1	89.3	89.3
- ϵ_m (%)	22.6	21.6	22.2	20.6	21.0	21.9	21.9
- ϵ_b (%)	32.3	30.7	31.6	29.2	29.7	31.2	31.2
Temperature (°F)	91.8	92.6	91.8	90.0	89.0	88.8	88.5

Visual Observations

1. Forward Bondline — Boot termination to propellant separation. 3/32" at 0°; 1/8" at 90°; 3/32" at 180°; 1/8" at 270°. Boot termination lifting 1/32" at 180°. degraded liner is present.

2. Aft Bondline — SD 844-1 is degraded, soft and tacky. Boot to propellant separation 0° unobserved due to slump, 11/32" at 90°; 5/16" at 180°; 11/32" at 270°. Boot lifting 1/16" at 180°; 3/32" at 220°; 1/16" at 270°.

3. Forward Bore — Small scratches on all fin rays. Nick at 310°, 1/2" x 1/4", 7" from boss. White fin material in bottom of fin slots at 0°, 60°, 250°, 300°. Forward propellant slump of 1/8".

4. Cylindrical Bore — Moderate coating of AP crystals.

5. Aft Nozzle Well — Voids 90°, 1/4", 8" in; 100°, 9/16" x 3/8", 3" in; 270°, 3/16", 2-1/2" in; 300°, 1/16", 1-1/2" in. Few scratches and light dusting of AP crystals.

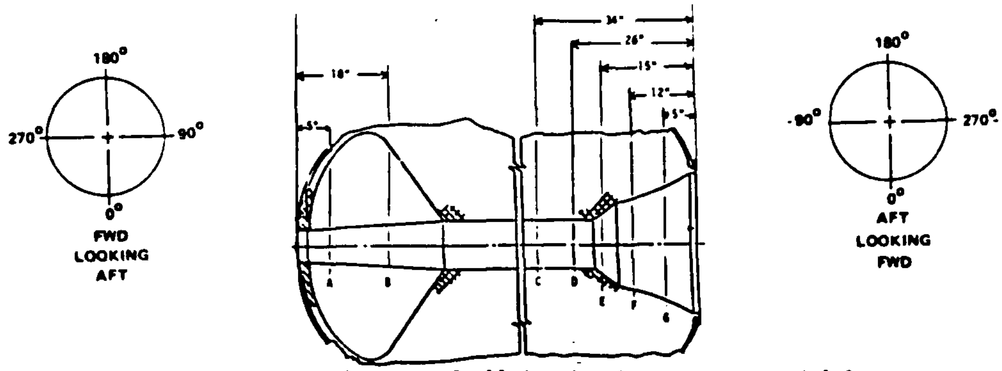
6. Other

Figure A-19. Summary of On-Surface Tests Conducted on Minuteman Stage II Motors, Sheet 11 of 13

Report 0162-06-SAAS-35, Appendix A

Motor SN: R7-014 (POA 6-109) Cast Date: 8 July 1985 CTPB Vendor: Phillips

Test Date: 16 August 1985 Bay Temp: 72°F Age at Test: 1 (Mos)



Average of All Angular Locations at Axial Location:

	A	B	C	D	E	F	G
Shore A2	46.5	53.8	53.8	53.5	57.0	54.5	55.3
On-Surface (K_{77})	27.8	30.9	27.6	27.4	21.9	23.7	22.3
- E_o (psi)	709.3	793.8	703.9	698.5	554.1	600.6	564.4
- σ_m (psi)	89.8	92.5	89.6	89.5	84.7	86.2	85.0
- ϵ_m (%)	21.7	20.4	21.7	21.8	24.5	23.6	24.3
- ϵ_b (%)	30.8	28.8	30.9	31.1	35.2	33.7	34.9
Temperature (°F)	73	73	73	72	74	74	74

Visual Observations

1. Forward Bondline — No discrepancies.

2. Aft Bondline — No discrepancies.

3. Forward Bore — Scratch 12 in. long on 90° fin ray. Small piece of fin material in bottom of 300° fin slot.

4. Cylindrical Bore — Slight propellant dust throughout.

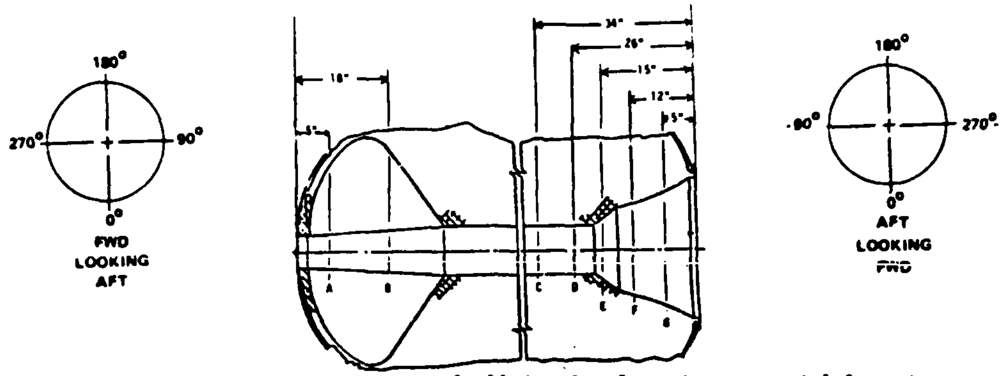
5. Aft Nozzle Well — Voids: 110°, 1/4 in. at aft propellant termination
340°, 1/8 in., 7 inches in.

6. Other — Rough polymer surface in fin slots.

Figure A-19. Summary of On-Surface Tests Conducted on Minuteman Stage II Motors, Sheet 12 of 13

Motor SN: R7-017 Cast Date: 22 July 1985 CTPB Vendor: Phillips

Test Date: 30 August 1985 Bay Temp: 79°F Age at Test: 1 (Mos)



Average of All Angular Locations at Axial Location:

	A	B	C	D	E	F	G
Shore A2	47.8	53.8	57.8	57.3	61.5	60.8	61.3
On-Surface (K_{77})	30.7	31.5	29.3	30.7	26.0	25.5	31.2
- E_o (psi)	787.7	810.4	749.9	787.7	661.1	647.9	802.1
- σ_m (psi)	92.3	93	91.1	92.3	88.2	87.8	92.8
- ϵ_m (%)	20.5	20.2	21.0	20.5	22.5	22.7	20.3
- ϵ_b (%)	28.9	28.5	29.8	28.9	32	32.4	28.7
Temperature (°F)	80.5	81.3	82.5	81.8	81.5	81.8	81.3

Visual Observations

1. Forward Bondline — No discrepancies.

2. Aft Bondline — No discrepancies.

3. Forward Bore — Rough polymer surface in fin slots. Small amount of fin material in all fin slots except 180°. 1/8" propellant slump. Few light scratches on all fin rays.

4. Cylindrical Bore — No discrepancies.

5. Aft Nozzle Well — Gouge 1/2" dia. at 175°, 3" in. Sprues have release agent in margins. Voids: 1/8" at 90°, 1/8" to 1/32" at 160°, 1/8" at 200°, 1-1/2" at 250°, 1/8" - 3/8" at 270°.

6. Other — None

Figure A-19. Summary of On-Surface Tests Conducted on Minuteman Stage II Motors, Sheet 13 of 13

Ignitability Testing Summary for This Report Period:

Motor AA 20402

Excise samples were removed from motor AA 20402 on 4/1/85. Visual inspection prior to sample excise indicated normal fin slot surfaces with a light coating of AP crystals. SEM examination of excised samples shows a highly three dimensional surface with free oxidizer crystals on the surface. The polymer surface layer appears to be relatively intact. The IDM was conditioned at 80°F - 80%RH for 24 hours prior to firing. A longer than average ignition delay (0.132 sec) was predicted from the IDM data. This prediction is consistent with the condition of the propellant.

Motor AA 20629

Motor AA 20629 is identified elsewhere in this report as the "Cracked Motor." Excise samples were taken from this motor on 5/14/85. Visual examination prior to sample excise indicated a rough, pitted surface in the upper fin slot areas. The surface polymer appears to be missing in some areas. SEM examination indicates a highly three dimensional surface with many pits and much free material (AP and Al) on the surface. The surface condition may be an artifact of core stripping since all surface features appear to be bound by a polymer film. The IDM was over conditioned at high humidity prior to firing and firing data is considered anomalous.

Motor AA 21480

Motor AA 21480 is one of two MM II motors identified as "Plug Motors." This motor was manufactured in 1976. Excise samples were taken from this motor on 6/27/85. Visual examination prior to sample excise indicated a rough, abraded surface in the fin slots. Very little AP coverage (5%) was observed on the finocyl surfaces. SEM examination shows a moderately three dimensional surface with a mostly intact surface polymer layer. A notable feature appearing in several of the SEM photographs is a series of linear cracks in the polymer surface. These cracks are similar to those caused by localized stress ("stress checks") in other propellant samples. The orientation of the cracks to the grain is unknown.

Figure A-20. Ignitability Testing Summary for This Report Period, Sheet 1 of 3

The IDM was conditioned at 80°F - 80%RH for 24 hours prior to firing. A normal
(0.113 sec) ignition delay was predicted from the IDM data.

Motor AA 21321

Motor AA 21321 has been identified as one of the "Early Age-Out" motors. It is ten years old. Excise samples were removed from this motor on 7/8/85. Visual examination prior to sample excise revealed scratches on all fin slot surfaces, rough fin slot surfaces, and a moderate coating of AP on the fin slot surfaces. The surfaces of the excised samples were rough and pitted over 35% of their area. SEM examination revealed a relatively planar surface with patches of very rough, exposed area. The topography of the rough areas suggests that they are artifacts of the core stripping process. AP crystal growth appears heavy in these rough areas.

The IDM was conditioned at 80°F - 80%RH prior to firing. A longer (0.122 sec) than normal ignition delay was predicted from IDM data. This propellant surface would be sensitive to exposure to high humidity environments.

Motor R6-072

Excise samples were taken from Motor R6-072 on 4/15/85. Visual examination prior to sample excise revealed very rough surfaces at the top of the fin slots. The roughness is caused by the finish of the released cores in that area and subsequent damage to the surface during the core stripping process. The appearance of the propellant surface in this area is not typical of the released surfaces in the rest of the motor. SEM examination reveals a surface that is very smooth over 65% of its area and very rough over the remainder. An acceleration in the rate of degradation with exposure to high humidity could be expected in the upper fin slots.

The IDM was conditioned at 80 - 80%RH for 24 hours prior to firing. The ignition delay prediction of 0.128 sec is longer than normal for this age motor.

Figure A-20. Ignitability Testing Summary for This Report Period, Sheet 2 of 3

Motor R6-069 (PQA 6-108)

A prefire report, as required by contract, was issued for R6-069 on 7/17/85. Excise samples were taken from this motor on 6/12/85. Visual examination prior to sample excise revealed the rough surfaces at the top of the fin slots previously noted in the discussion on Motor R6-072. SEM results are also similar to those for R6-072. The IDM was conditioned at 80°F - 80%RH for 24 hours prior to firing. The predicted ignition delay was 0.127 sec.

The IDM data for R6-069 is considered anomalous: the IDM never attained 350 psi and the pressurization rate was low (1556 psi/sec). No cause for the abnormal values has been identified as yet and the firing of the motor at AEDC was not accomplished during this reporting period.

Motor R7-014 (PQA 6-109)

Excise samples from Motor R7-014 were taken on 8/19/85. Visual examination prior to sample excise the same rough surfaces in the upper fin slot area as noted previously. Release material embedded in the propellant was also visible. SEM examination was not completed during this reporting period; the prefire report is pending. The IDM was conditioned at 80°F - 80%RH for 24 hours prior to firing. IDM data indicates a slightly shorter ignition delay than normal (0.099 sec vs a 0.103 sec PQA average).

Figure A-20. Ignitability Testing Summary for This Report Period, Sheet 3 of 3

Motor No.	Age (Mos)	CTPB	PREDICTION	ACTUAL(1)	% ERROR	REMARKS (VISUAL AND SEM)
AA 20011	197	GTR	0.116	NA	-	Rough Surface - No Crystals
AA 20026 (OP-59)	206	GTR	0.142	0.102	39	No Crystals-Mostly Smooth-Slight Reddish Color
AA 20033 (OP-58)	203	GTR	0.113	0.106	24	Relatively Smooth Surface-Some Small Crystals and Degradation
AA 20043 (OP-60)	209	GTR	0.113	0.126	101	Light Covering of Small Crystals Observed at Hill AFB. None Observed on Samples Used for Testing.
AA 20045 (OP-57)	197	GTR	0.111	0.115	3	Relatively Smooth Surface - No Crystals
AA 20051 (OP-56)	192	GTR	0.112	0.098	14	Some Gouges & Small Crystals-Generally Rough Surface
AA 20053	180	GTR	0.081	NA	-	Normal Appearing with Scrape Marks
AA 20074 (OP-61)	210	GTR	0.114	0.097	18	Some Surface AP Crystals-Early Signs of Degradation
AA 20077	181	GTR	0.104	NA	-	Normal Appearing
AA 20083	181	GTR	0.095	NA	0	Reddish Color to Surface-Degraded Polymer
AA 20086	180	GTR	0.092	NA	0	Very Fine Layer of Crystals Over Surface
AA 20094 (OP-53)	179	Phillips	0.105	0.106	1	Some Surfaces with Degraded Polymer
AA 20095 (OP-62)	199	Phillips	0.074	0.101	29%	Small Amount of Red Coloring-Sample Damaged by Excising
AA 20100	180	Phillips	0.108	NA	-	Reddish Color to Surface-Degraded Polymer
AA 20101 (OP-63)	216	Phillips	0.114	0.094	20	Reddish, Rough with Sticky Brown Surface
AA 20143	216	Phillips	0.120	NA	-	Rough Texture
AA 20145	179	Phillips	0.113	NA	-	Normal Appearing-Some Rough Spots on Surface
AA 20167 (OP-55)	183	Phillips	0.101	0.096	5	Normal Surface-Some Rough Spots
AA 20177	177	Phillips	0.086	NA	-	Some Surface With Degraded Polymer
AA 20216	177	GTR	0.130	NA	-	Very Degraded Surface with Crystals
AA 20226	178	Phillips	0.106	NA	-	Smooth Dull Surface-Normal Brownish Color

Figure A-21. Ignitability and SEM Results for Minuteman Stage II Motors, Sheet 1 of 3

AA 20261	171	Phillips	0.098	NA	-	Surface Polymer Layer Slightly Degraded
AA 20263	176	Phillips	0.100	NA	-	Normal Appearing-Some Small Crystals
AA 20288	182	Phillips	0.106	NA	-	Shiny (Glassy) Surface-No Crystals
AA 20301	190	Phillips	0.127	NA	-	No Crystals
AA 20369	197	GTR	0.118	NA	-	Light Gray in Color
AA 20415		GTR	0.150	NA	-	Reddish Color-Relatively Smooth
AA 20419	203	GTR	0.118	NA	-	Normal Surface-Few Crystals
AA 20436	176	GTR	0.125	NA	-	Few Scattered Crystals
AA 20442	192	GTR	0.111	NA	-	Large Amount of Crystal Formation
AA 20473	195	GTR	(Inadequate to Test Samples)			Grayish White with Fine Crystals Over 70% of Surface
AA 20479	176	GTR	0.110	NA	-	Some Small Crystals in Isolated Spot
AA 20488	192	GTR	0.122	NA	-	Light Gray with Powdery Texture
AA 20559	81	GTR	0.118	NA	-	15% Red Discoloration
AA 20579	166	GTR	0.117	NA	-	Slightly Rough with Some Reddish Color
AA 20617	160	GTR	0.110	NA	-	Reddish Color-Crystals on All Surfaces and Rough
AA 20637	160	GTR	0.124	NA	-	Some Small Oxidizer Crystals-Reddish Color
AA 20106	222	Phillips	0.067	NA	-	Reddish Discoloration and Scuffing
AA 20114	221	Phillips	0.114	NA	-	Reddish Discoloration-Scuffing/Crosshatch
AA 20493	200	GTR	0.102	NA	-	None
AA 20149	138	GTR	0.119	NA	-	None
AA 20596	193	GTR	0.110 0.127 0.117	NA	-	Excessive AP on Finocyl Surfaces Visually Observed; Surface of Samples was Scrubbed by Excise Tooling
AA 20613	208	Phillips	0.107	NA	-	Rough Surface; AP
AA 20530	203	GTR	0.108	NA	-	Rough, Pitted Surface
R2-017 (PQA 6-92)	0	Phillips	0.102	0.103	1	One Surface with Pool Release
R2-033 (PQA 6-93)	0	Phillips	0.095	0.100	5	Normal Appearing-Slightly Disrupted Polymer
R2-036 (LC-77)	0	Phillips	0.095	NA	-	Normal Appearing-Slightly Rough Surfaces
R2-039 (PQA 6-94)	0	Phillips	0.115	0.106	8	Normal Appearing
R2-054 (LC-78)	0	Phillips	0.092	0.100	8	Rough Surface-Poor Release and No Crystals
R3-007 (PQA 6-95)	0	Phillips	0.106	0.103	3	Normal-Smooth
R3-013 (LC-79)	0	Phillips	(2)	NA	-	Rough-Poor Release, No Crystals

Figure A-21. Ignitability and SEM Results for Minuteman Stage II Motors, Sheet 2 of 3

R3-030 (PQA 6-96)	0	Phillips	0.113	0.111	2	No Crystals-Mostly Rough Surfaces (Poor Release)
R3-042 (LC-80A)	0	Phillips	0.107	NA	-	No Crystals-Mostly Rough Surfaces
R3-062 (PQA 6-98)	0	Phillips	0.097	0.102	5	No Crystals-Mostly Rough Surfaces (Poor Release)
R4-009 (LC-81)	0	Phillips	0.102	NA	-	No Crystals-Mostly Smooth-Slightly Greenish Color
R4-022 (PQA 6-99)	0	Phillips	0.107	0.100	7	Normal Appearing-Slightly Rough-Possibly Damaged During Excising
R4-036 (LC-82)	0	Phillips	0.126	NA	-	Orange Peel Surface-Not Degraded
R4-037 (PQA 6-100)	0	Phillips	0.112	0.102	10	Rough Surface-Possibly Damaged During Excise
R4-052 (LC-83)	0	Phillips	0.107	NA	-	Some Debris-Not Degraded
R4-061 (LC-83)	0	Phillips	0.121 (3)	NA	-	
R4-065 (PQA 6-101)	0	Phillips	0.1119	0.100	19%	Few Tiny Green Specks
R5-008 (PQA 6-102)	0	Phillips	0.115	NA	-	Few Green Particles on Surface
R5-027 (PQA-103)	0	Phillips	0.122	NA	-	No Release and No Discoloration
R6-002	0	Phillips	0.133	NA	-	None
R6-018 (LC-86A)	0	Phillips	0.158	NA	-	Indentations and Scratches
R6-005 PQA 6-105	0	Phillips	0.071	0.0907	27%	White Powdery Surface
R5-048A (PQA 6-106)	0	Phillips	0.117	0.101	14	White Powder; Rough Surface
R6-051	0	Phillips	0.099	0.107	0	Rough Surface; Embedded Styrofoam
R6-049 (LC-87)	0	Phillips	0.101	NA	-	Rough, Pitted Surface

The following motors were tested this report period.

AA 20402	217	GTR	0.132	NA	-	Free Crystals on Surface
AA 20629	197	Phillips	Bad Firing	NA	-	Over Conditioned at High RH
AA 21480	110	Phillips	0.113	NA	-	Normal
AA 21321	132	GTR	0.122	NA	-	Rough, Pitted Patches on Surface
R6-072 (LC-88)	0	Phillips	0.128	NA	-	Rough, Atypical of Finocyl
R6-069 (PQA 6-108)	0	Phillips	0.127	Pending	-	Poor Ignition; Samples Atypical of Finocyl
R7-014 (PQA 6-109)	0	Phillips	0.099	Pending	-	Rough; Atypical of Finocyl

Figure A-21. Ignitability and SEM Results for Minuteman Stage II Motors, Sheet 3 of 3

SUMMARY OF TEST RESULTS
MOTORS AA21049 vs AA21321

	TYPE TEST	AA21049	AA21321
BOND SYSTEM	BOND TENSILE	19 - 34, below average	12 - 27, below average; < 14 psi is totally degraded
SD-851-2 LINER	SWELLING RATIO	2.340	>2.5
	GEL-FILLER FRACTION	0.234	0.036
	FTIR	no new peaks	no new peaks
V-45 INSULATION	SWELLING RATIO	1.68	1.64
	GEL-FILLER FRACTION	0.889	0.891
	% DOP	1.46	1.59
	RELAXATION MODULUS, psi	2246	1961
ANB 3066 PROPELLANT	RELAXATION MODULUS, psi	434 - 572, typical	256 - 350, soft; no value obtained at bondline interface
	TENSILE MODULUS, psi	typical (bore)	typical (bore)
	TENSILE MODULUS, psi	typical (bondline)	low strength (bondline)
	FTIR	n/a	high concentration of extractables at bondline interface
	IGNITABILITY	slightly slower than new motors	slightly slower than new motors
	ON-SURFACE TEST	typical	soft

Figure A-22. Summary of Test Results: Motor AA21049 vs Motor AA21321

MECHANICAL PROPERTIES OF M/M EXCISED SAMPLES
(ORIGINAL PRODUCTION)

MOTOR NO	OP	AGE MOS.	CTPB	BOND TENSILE	ER1 PROP	ER1 V-45	DENSITY	SWELLING RATIO	GEL FILLER FRACTION	% H2O	% DOP	SHORE A	SWELLING RATIO	GEL FILLE FRACTION
20011		198	GTR	33	385	2006	1.230	1.670	0.909	2.06	1.20	73	2.400	0.280
20013		125	GTR	18	232	4601				2.05		76	2.150	
20026	59	206	GTR	15	328	2141	1.219	1.680	0.896	2.06		73		0.150
20028	45	156	GTR	20	402	2886				1.84		73		0.326
20029		123	GTR	24	303	2276				1.92			2.050	
20033	58	203	GTR		258	1616		1.700		1.96	1.00	67		0.211
20035		123	GTR	33	346	896				2.06		71	2.050	
20041	43	148	GTR	30	390	1958		1.728	0.889			73	2.360	0.323
20042	35	142	GTR	19	362	1870	1.230			1.89		63	2.350	
20043	60	209	GTR	22	329	2800	1.228	1.660	0.891	2.12	1.20			0.393
20045	57	197	GTR	19		2075		1.710	0.895	2.18	1.30	72		0.104
[illegible]			GTR	24	352	1696		1.726	0.891	1.85		70	2.310	0.448
20051	56	192	GTR	32	326			1.680	0.904	1.86	1.20		2.220	0.468
20053		186	GTR	21	277	2556	1.231	1.660	0.898	1.95	1.21	74		0.385
20071	28	123	GTR	36	346	1424				1.92		64	2.200	
20074	61	210	GTR	28	468	1930	1.217	1.710	0.902	2.04	1.20	79		0.304
20077		181	GTR	33	461	1715	1.232	1.670	0.899	1.62	1.21			0.257
20080	46	154	GTR	14	344	1307				1.92		75		
20083		181	GTR	15	385	2858	1.231	1.700	0.892	1.89	1.13		2.500	0.237
20086		181	GTR	35		1568	1.228	1.720	0.892	1.98	1.28	73		0.139
20094	53	177	PHIL	24	1098	1842	1.229	1.670	0.892	1.82	1.60	69		0.375
20095	62	199	PHIL	25	722	2282								
20097	27	122	PHIL	42	604	1834				1.91		70	2.120	
20098	50	169	PHIL	29	769	1462	1.158	1.670	0.890	1.95				
20099	51	175	PHIL	25	627	2172	1.230	1.710	0.881	2.03	0.90		2.280	0.351
20100		181	PHIL	24	930	2099	1.226	1.700	0.888	1.82	1.40	67		0.410
20101	63	216	PHIL	18	772	1964			0.895		1.16		1.920	0.418
20103	34	138	PHIL	34	885	1142				1.70		70	2.220	
20104	54	177	PHIL	28	938	2234		1.710	0.907	2.01	0.60			0.235
20106		222	PHIL	28	915	2908			0.896		1.50			0.160
20107		182	PHIL	27	1179	2540	1.233	1.680	0.907	2.23	1.10	68		0.429
20108	49	165	PHIL		1032	2424		1.707	0.883	1.90			2.372	0.488
20110	47	156	PHIL	31	1119					1.90			2.370	0.364
20114		122	GTR	36	444	1911				1.83		69	2.100	
20114		221	GTR	27	506	2530			0.896		1.60			0.185
20118		116	GTR	26	368	2212				2.10			2.110	
20125		181	GTR	28	445	2380	1.235	1.690	0.899	1.97	1.50	74		0.413
20143		120	PHIL	42	974	2156				1.87		68	2.050	
20143		216	PHIL	28	1073	2870			0.896		1.00		2.300	0.312
20144		191	GTR	36	604	2018	1.230	1.740	0.891	2.00	1.30	79	2.360	0.332
20147		121	PHIL	20	836	2642				1.91			2.280	
20161		114	PHIL	25	1321	950				2.05			2.120	
20167	55	183	PHIL	33	803	2010	1.223	1.680	0.890	2.06	1.20	67	2.390	0.299
20182	48	156	PHIL	22	1264	2279		1.674	0.887	2.03			2.500	0.231
20184		137	GTR	31	468	1726				1.84		75	2.340	
20189		116	GTR	39	308	1983				1.88		70	2.000	
20192		137	GTR	34	313	2006				1.82		73	2.130	
20204		112	GTR	40	492	2388				2.04		72	2.020	
20209		114	PHIL	44	1014	1459				1.74			2.010	
20224		176	GTR	33	345	2350							2.500	0.232
20226		178	PHIL	15	933	2059	1.228	1.630	0.893	2.00	1.10		2.010	0.334

Figure A-23. Mechanical and Chemical Properties of Minuteman Excised Samples (Original Production), Sheet 1 of 3

MECHANICAL PROPERTIES OF M/M EXCISED SAMPLES
(ORIGINAL PRODUCTION)

MOTOR NO.	OP	AGE MOS.	CTPB	BOND TENSILE	ER1 PROP	ER1 V-45	DENSITY	SWELLING RATIO	GEL FILLER FRACTION	% H2O	% DOP	SHORE A	SWELLING RATIO	GEL FILLER FRACTION
20261		171	PHIL	29		2078	1.225	1.690	0.887	2.01	1.60			0.268
20263		176	PHIL	30	1081	3651	1.227	1.660	0.899	1.85	1.30	73	2.340	0.318
20267		115	PHIL	38	1011	2580				1.92			2.000	
20275		114	PHIL	47	1115	2109				1.85			2.000	
20288		176	PHIL	24	898	2108	1.224	1.670	0.880	1.91		74	2.360	0.264
20295		106	GTR	22	416	3452				1.98		75	2.180	
20301		190	PHIL	12	408	2645	1.240	1.690	0.905		1.10	74		0.036
20330		112	PHIL	41	895	1712				1.77			2.020	
20332		110	GTR	35	499	1977				1.92		68	2.050	
20355		109	GTR	30	469	1594				1.95		65	2.020	
20369		197	GTR	31	470	2124			0.907		1.40			0.073
20369		108	GTR	27	530	2269				1.92		72	2.130	
20402		216	GTR	21	424	2156			0.897		1.60		2.040	0.273
20415		180	GTR	15	358	2103		1.710	0.883		1.30	71		0.276
20419		203	GTR	22		2896			0.900		1.10			0.252
20424		105	GTR	32	492	2115				2.06		69	1.910	
20436		189	GTR	21	474	3123	1.230	1.660	0.886	2.37	1.40	67		0.346
20442		106	GTR	42	732	2100				1.84			2.050	
20442		192	GTR	33	579	2264			0.902		1.20		1.990	0.329
20472	31	103	GTR	60	427	2010				1.75			1.900	
20473		195	GTR	23	463	2050			0.903		1.20		2.270	0.358
20479		167	GTR	14	400	1892	1.236	1.670	0.895	2.07	1.60			0.325
20488		192	GTR	30	496	1176			0.894		1.40		2.120	0.449
20493		100	GTR	52	529	1642				1.73		65	1.990	
20493		200	GTR	37	482	2138			0.898		1.40		2.300	0.341
20508		98	PHIL	36	640	1997				1.78		65	1.850	
20515		97	GTR	52	583	1644				1.72		68	1.980	
20530		203	GTR	40	406	1854			0.898		1.20		1.990	0.428
20554		91	GTR	42	360	1833				1.73		63	2.080	
20559		90	GTR	39	472	1930				1.90		68	1.840	
20559		181	GTR	26	311	2394			0.894		1.20		2.100	0.453
20567		89	GTR	42	398	2275				1.96		71	1.940	
20579		88	GTR	42	440	1328				1.70		59	1.990	
20579		167	GTR	30	396	1924	1.243	1.690	0.895		1.30	68		0.330
20587		83	PHIL	32		1800				2.11		67	2.230	
20596		192	GTR	41	339	2236			0.893		1.40		2.110	0.402
20598		83	PHIL	52	807	1800				1.80		64	1.940	
20613		194	PHIL	39	1008	1777			0.899		1.10		2.100	0.361
20615		160	GTR	34	392	1649	1.237	1.690	0.888	2.02	1.50	75		0.444
20616		84	GTR	55	338	2186				1.77		68	1.950	
20621		84	GTR	56	358	1251				1.93		65	1.880	
20629		196	PHIL	35	774	2406			0.885		1.40		2.440	0.270
20637		164	GTR	21	353	2380						63		
20672		79	GTR	63	489	1514				1.80		66	1.850	
20715		73	PHIL	48	631	1452				1.86		63	1.920	
20726		71	GTR	53	708	1385				1.74		59	1.950	
20745		68	GTR	57	557	2201				1.92		65	1.860	
20759		67	PHIL	55	875	1110				1.81		52	1.850	
20785		64	GTR	50	671	1808				1.75		62	1.890	
20788		64	GTR	70	561	1679				1.65		61	1.870	

Figure A-23. Mechanical and Chemical Properties of Minuteman Excised Samples (Original Production), Sheet 2 of 3

20846		57	PHIL	59	875	1696				1.87		54	1.790	

MECHANICAL PROPERTIES OF M/M EXCISED SAMPLES
(ORIGINAL PRODUCTION)

MOTOR NO.	OP	AGE MOS.	CTPB	BOND TENSILE	ER1 PROP	ER1 V-45	DENSITY	SWELLING RATIO	GEL FILLER FRACTION	% H2O	% DOP	SHORE A	SWELLING RATIO	GEL FILLER FRACTION
20860		57	GTR	61	764	1630				1.73		57	1.930	
20888		54	PHIL	57	820	2057				1.77		68	1.840	
20925		51	PHIL	72	794	2177				1.65		62	1.850	
20971		47	GTR	67	490	2556				1.84		65	1.810	
20987		44	GTR	47	506	2508				1.96		74	1.840	
21049		138	GTR	26	491	2246			0.889		1.50		~ 340	0.234
21321		138	GTR	19	290	1961		1.640	0.891	1.77	1.59	74		0.036
21480		108	P					1.640	0.890	1.77	1.67		1.890	0.454
MS-4		142	PHIL	34	590	2388				1.90		64	2.210	
QT-11		126	GTR	16	363	3657				1.86				
QT-SP2		130	GTR	12	207	3315				2.18			2.140	

Figure A-23. Mechanical and Chemical Properties of Minuteman Excised Samples (Original Production), Sheet 3 of 3

STAGE II LINER BOND TEST DATA
PROVIDED BY HILL AFB

MOTOR NUMBER	PROPELLANT LOT #	AGE MO	AVERAGE SWELL	GEL #1	MAX STRESS
21034	52G	82	2.0265	0.588	51.91
21048	52G	81	1.8855	0.500	53.62
21057	53P	80	1.9565	0.515	53.16
21070	53P	80	1.7100	0.624	67.38
21083	54P	90	1.8230	0.620	62.40
21086	51P	86	1.9425	0.612	60.39
21098	51P	84	1.6785	0.515	47.45
21109	54P	88	1.9710	0.614	46.31
21121	55G	82	1.9165	0.553	42.74
21125	55G	82	1.8875	0.552	41.25
21179	58G	81	1.7375	0.618	70.36
21201	57P	75	2.0445	0.573	49.60
21210	58G	79	1.8260	0.645	56.42
21215	57P	74	1.8605	0.621	48.94
21260	59G	71	2.3050	0.408	20.97
21283	59G	70	1.7090	0.570	53.50
21295	60G	69	1.9340	0.549	47.59
21310	61P	68	1.8230	0.564	45.68
21321	60G	67	2.1660	0.456	28.14
21328	61P	66	1.9710	0.504	41.30
21333	62P	70	1.9145	0.649	47.95
21345	62P	69	1.8240	0.638	52.68
21363	63P	68	1.8050	0.567	56.41
21379	63P	62	1.8880	0.685	57.33
21442	66P	45	1.6800	0.615	63.83
21460	66P	42	1.7110	0.679	95.64
21466	67P	41	1.7990	0.689	97.20
21487	67P	37	1.6580	0.677	86.23
21499	68P	45	1.9250	0.683	66.69
21516	68P	42	1.8190	0.693	77.46
21525	69P	40	1.7740	0.630	57.29
21547	69P	37	1.8310	0.647	73.36
21573	71P	21	1.5985	0.663	83.02
21585	71P	19	1.7285	0.706	85.48
21588	72P	19	1.7105	0.714	86.47
21590	72P	17	1.6900	0.696	80.49

Figure A-24. Stage II Liner Bond Test Data Provided by Hill AFB

Test Temperature: 77°F
Strain Rate: 0.74 min^{-1}

		Forward					Mid Barrel					Aft				
Age, mo	Location, Degrees	σ_m, psi	ϵ_m, %	ϵ_b, %	E_o, psi	SA	σ_m, psi	ϵ_m, %	ϵ_b, %	E_o, psi	SA	σ_m, psi	ϵ_m, %	ϵ_b, %	E_o, psi	SA
12	30	138	21	32	1015	57	128	19	32	1227	60	131	18	31	1267	61
	210						129	19	33	1135						
18	75	135	20	29	1160	61						135	16	27	1369	63
24		✓					✓									
30		✓					✓					✓				
36		✓										✓				
48		✓					✓					✓				
72		✓					✓									
96							✓					✓				
120		✓										✓				
144		✓					✓					✓				

Sample Location ⟶ Forward, Mid Barrel, Aft

✓ Designates Scheduled Test Intervals

Figure A-25. Effect of Sample Location and Storage Time on Uniaxial Tensile Properties or Propellant from Motor MSEX-2

2ı4

Test Temperature: 77°F
Applied Strain: 2.0%

		Sample Location								
		Forward			Mid Barrel			Aft		
		Relaxation Modulus, E_r, psi at Time t, Minutes			Relaxation Modulus, E_r, psi at Time t, Minutes			Relaxation Modulus, E_r, psi at Time t, Minutes		
Age mos	Location	0.1	1.0	10.0	0.1	1.0	10.0	0.1	1.0	10.0
	30°				787	507	387			
12	210°	748	491	385	848	538	406	936	612	472
18	75°	967	629	493				1094	722	569
24										
30										
36										
48										
72										
96										
120										
144										

Figure A-26. Effect of Sample Location and Storage Time On Relaxation Modulus of ANB-3066 Propellant, Motor MSEX-2 (1984A)

Test Temperature: 77°F
Strain Rate: 1.0 min^{-1}

Property	Sample Location	Age mo	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.5	2.0	2.5	3.0	3.5	4.0
			Distance from Bondline, Inches															
σ_m, psi	Forward (30°)	12	141	144	145	149	148	142	141	144	150	139	134	125	132	130	130	132
	(75°)	18	116	124	130	130	132	134	135	134	136	134	131	122	122	120	119	120
		24																
		36																
		48																
		72																
		120																
		144																
	Mid Barrel (30°)	12	149	130	136	135	129	126	135	132	131	129	124	122	123	120	114	121
	(210°)	12	133	129	120	129	135	128	129	129	128	128	121	128	124	123	121	123
		24																
		70																
		48																
		72																
		96																
		144																
	Aft (30°)	12	144	136	133	133	133	132	132	131	131	131	130	126	124	122	121	121
	(75°)	18	136	125	122	122	124	124	126	124	124	124	126	125	122	122	121	121
		30																
		36																
		48																
		96																
		120																
		144																

Figure A-27. Effect of Sample Location, Storage Time and Distance from Bondline on Uniaxial Tensile Properties of ANB-3066 Propellant, Motor MSEX-2 (1984A), Sheet 1 of 4

Test Temperature: 77°F
Strain Rate: 1.0 min^{-1}

Property	Sample Location	Age mo	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.5	2.0	2.5	3.0	3.5	4.0
			Distance from Bondline, Inches															
ϵ_m, %	Forward (30°)	12	10	16	19	21	21	22	22	21	21	20	21	21	21	20	20	21
	(75°)	18	10	16	19	20	20	20	20	18	18	18	19	18	17	18	18	19
		24																
		36																
		48																
		72																
		120																
		144																
	Mid Barrel (30°)	12	12	18	19	19	20	21	21	19	21	20	20	20	18	19	20	19
	(210°)	12	10	16	18	18	18	19	19	20	19	20	20	19	20	21	20	20
		24																
		30																
		48																
		72																
		96																
		144																
	Aft (30°)	12	10	15	18	19	19	20	20	21	20	19	18	18	18	17	18	18
	(75°)	18	10	17	18	19	19	19	19	19	19	18	17	16	16	16	16	17
		30																
		36																
		48																
		96																
		120																
		144																

Figure A-27. Effect of Sample Location, Storage Time and Distance from Bondline on Uniaxial Tensile Properties of ANB-3066 Propellant, Motor MSEX-2 (1984A), Sheet 2 of 4

Test Temperatures: 77°F
Strain Rate: 1.0 min^{-1}

Property	Sample Location	Age mo	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.5	2.0	2.5	3.0	3.5	4.0
			Distance from Bondline, Inches															
ϵ_b, %	Forward (30°)	12	10	24	28	29	30	29	29	28	31	28	29	28	27	30	28	30
	(75°)	18	10	20	28	29	29	29	28	26	26	26	26	24	25	25	25	25
		24																
		36																
		48																
		72																
		120																
		144																
	Mid Barrel (30°)	12	12	18	19	19	20	21	21	19	21	20	20	20	18	19	20	19
	(210°)	12	10	25	29	29	29	29	29	31	29	31	27	30	32	30	32	33
		24																
		30																
		48																
		72																
		96																
		144																
	Aft (30°)	12	11	24	30	31	31	30	30	30	29	29	30	30	30	29	27	29
	(75°)	18	10	24	29	29	28	28	30	29	26	26	26	26	26	27	26	28
		30																
		36																
		48																
		96																
		120																
		144																

Figure A-27. Effect of Sample Location, Storage Time and Distance from Bondline on Uniaxial Tensile Properties of ANB-3066 Propellant, Motor MSEX-2 (1984A) Sheet 3 of 4

Test Temperature: 77°F
Strain Rate: 1.0 min^{-1}

Property	Sample Location	Age mo	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.5	2.0	2.5	3.0	3.5	4.0
			Distance from Bondline, Inches															
E_o, psi	Forward (30°)	12	1703	1352	1181	1099	1018	972	959	972	1063	1010	957	876	935	972	943	906
	(75°)	18	1359	1191	1008	1088	1044	1008	1044	1034	1073	1016	1077	1086	1115	1044	1032	1035
		24																
		36																
		48																
		72																
		120																
		144																
	Mid Barrel (30°)	12	1525	1108	1085	1071	1003	965	1040	1063	1048	1039	1018	1041	1039	972	950	1017
	(210°)	12	1517	1219	1025	1116	1137	1055	1048	1010	1017	1063	958	1003	921	876	928	921
		24																
		30																
		48																
		72																
		96																
		144																
	Aft (30°)	12	1633	1373	1165	1151	1136	1135	1099	1070	1076	1076	1113	1106	1114	1091	1069	1046
	(75°)	18	1696	1169	1078	1090	1063	1005	1084	1074	1066	1022	1138	1162	1147	1124	1109	1083
		30																
		36																
		48																
		96																
		120																
		144																

Figure A-27. Effect of Sample Location, Storage Time and Distance from Bondline on Uniaxial Tensile Properties of Anb-3066 Propellant, Motor MSEX-2 (1984A) Sheet 4 of 4

Test Temperature: °F
Applied Strain: 2.0%

Property	Sample Location	Age mo	Distance from Bondline, Inches 0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.5	2.0	2.5	3.0	3.5	4.0
E_{r_1}, psi	Forward (30°)	12	1007	692	553	543	526	534	552	471	482	461	497	518	437	458	459	449
	(75°)	18	954	621	574	533	552	570	557	573	605	590	576	678	670	636	690	666
		24																
		36																
		48																
		72																
		120																
		144																
	Mid Barrel (30°)	12	926	604	533	485	490	468	494	449	427	446	483	483	500	488	504	505
	(210°)	12	960	671	613	631	577	580	582	566	557	523	547	484	526	521	516	482
		24																
		30																
		48																
		72																
		96																
		144																
	Aft (30°)	12	963	659	610	576	575	577	597	560	549	523	508	556	578	600	577	571
	(75°)	18	1018	691	609	612	610	630	557	600	582	586	697	712	736	718	746	724
		30																
		36																
		48																
		96																
		120																
		144																

Figure A-28. Effect of Sample Location, Storage Time and Distance from Bondline on Relaxation Modulus of ANB-3066 Propellant, Motor MSEX-2 (1984A)

Type Test: Double Plate Tensile
Type Specimen: Mini Double Plate
Test Temperature: 77°F
Crosshead Rate: 0.5 in./min

Sample Location ⟶

		Forward						Mid Barrel						Aft					
				Type Failure, %						Type Failure, %						Type Failure, %			
Age mo	Location	Stress, psi	Time-to-Fail., min	CP	APL	CPI	ALI	Stress, psi	Time-to-Fail., min	CP	APL	CL	ALI	Stress, psi	Time-to-Fail., min	CP	APL	CL	ALI
12	30°	104	0.23		95	5		78	0.21		90	10		102	0.22		85	15	
	210°							105	0.21		90	5	5						
18	75°	98	0.19		80	20								120	0.18		85	15	
24																			
30																			
36																			
48																			
72																			
96																			
120																			
144																			

Figure A-29. Effect of Sample Location and Storage Time on Bond Tensile Strength of ANB-3066/SD-851-2/V-45 Bond System, Plug Motor MSEX-2 (1984A)

Type Test: High Rate Shear
Test Temperature: 77°F
Crosshead Rate: 200 in./min
Superimposed Pressure: 600 psig

	Sample Location ⟶	Forward						Mid Barrel						Aft					
Age mos	Location	Stress, psi	Time-to-Fail., sec	Type Failure, % CP	APL	CPI	ALI	Stress, psi	Time-to-Fail., sec	Type Failure, % CP	APL	CL	ALI	Stress, psi	Time-to-Fail., sec	Type Failure, % CP	APL	CL	ALI
12	30°	209	0.12		45	55		236	0.11		50	50		228	0.12		50	50	
	210°							243	0.13		45	55							
18	75°	219	0.09		35	65								224	0.10		50	50	
24																			
30																			
36																			
48																			
72																			
96																			
120																			
144																			

Figure A-30. Effect of Sample Location and Storage Time on Bond Shear Strength of ANB-3066/SD-851-2/V-45 Bond System, Plug Motor MSEX-2 (1984A)

LOCATION	TIME MONTH	TEMP F	DISTANCE INCHES	INITIAL WEIGHT	970/ IW	995/ IW	1295/ IW	1725/ IW	970/ 2850
MID BARREL (210 DEG)	12	80	0.0	1.0713	0.094	0.038	0.033	[illegible]	[illegible]
			0.1	1.0689	0.167	0.064	[illegible]	[illegible]	[illegible]
			0.2	1.0917	0.169	0.064	0.035	[illegible]	1.101
			0.3	1.0591	0.170	0.063	0.032	0.047	1.084
			0.5	1.0844	0.164	0.061	0.028	0.042	1.079
			2.0	1.0793	0.165	0.061	0.025	[illegible]	1.085
MID BARREL (30 DEG)	12	80	0.0	0.9969	0.091	0.036	0.032	0.051	0.910
			0.1	1.0805	0.163	0.061	0.036	0.055	1.107
			0.2	1.0307	0.170	0.065	0.035	0.052	1.108
			0.3	1.0394	0.169	0.063	0.032	0.051	1.114
			0.5	1.0911	0.170	0.064	0.029	0.045	1.088
			2.0	1.0406	0.161	0.058	0.020	0.036	1.098
FORWARD END (30 DEG)	12	80	0.0	1.0913	0.103	0.040	0.049	0.071	0.896
			0.1	1.0448	0.159	0.060	0.047	0.063	1.099
			0.2	1.0404	0.163	0.060	0.039	0.058	1.104
			0.3	1.0468	0.162	0.061	0.035	0.052	1.069
			0.5	1.0657	0.160	0.059	0.028	[illegible]	[illegible]
			2.0	1.0518	0.154	0.057	0.022	[illegible]	1.038
FORWARD END (75 DEG)	18	80	0.0	1.0415	0.131	0.068	0.057	0.078	1.172
			0.1	1.0920	0.179	0.082	0.054	0.070	1.250
			0.2	1.0728	0.173	0.073	0.044	0.062	1.177
			0.3	1.0773	0.182	0.082	0.046	0.059	1.233
			0.5	1.0736	0.168	0.072	0.033	0.048	1.161
			2.0	1.0943	0.164	0.073	0.027	0.039	1.162
AFT END (30 DEG)	12	80	0.0	1.0625	0.093	0.040	0.042	0.066	1.000
			0.1	1.0452	0.165	0.062	0.040	0.062	1.229
			0.2	1.0783	0.172	0.068	0.041	0.058	1.208
			0.3	1.0162	0.172	0.068	0.037	0.055	[illegible]
			0.5	1.0933	0.165	0.062	0.027	[illegible]	[illegible]
			2.0	1.0468	0.160	0.061	0.021	0.037	1.159
AFT END (75 DEG)	18	8	0.0	1.0753	0.113	0.059	0.050	0.071	1.052
			0.1	1.0982	0.173	0.076	0.050	0.066	1.218
			0.2	1.0801	0.181	0.082	0.052	0.065	1.250
			0.3	1.0745	0.176	0.078	0.044	0.058	1.219
			0.5	1.0900	0.176	0.075	0.035	0.049	[illegible]
			2.0	1.0748	0.170	0.078	0.030	0.040	1.188

Figure A-31. Plugs from Motor MSEX-2: Transmission Spectra of Chloroform Extractables, Peak Heights Normalized to Initial Weights (Gradient from Bondline Interface)

CHEMICAL PROPERTIES OF SD-851-2 LINER
PLUG MOTOR MSEX-II

PLUG MOTOR #	MOTOR LOCATION	AGE MONTHS	SWELLING RATIO	GEL-FILLER FRACTION *
MSEX-2	FORWARD END (30 DEG)	12	1.87	0.671
MSEX-2	AFT END (30 DEG)	12	1.70	0.670
MSEX-2	FORWARD END (75 DEG)	18	1.70	0.666
MSEX-2	AFT END (75 DEG)	18	1.84	0.699

Gel-Filler Fraction Corrected
for Variation in Thickness

Figure A-32. Chemical Properties of SD-851-2 Liner, Plug Motor MSEX-2

Test Temperature: 77°F
Applied Strain: 2.0%

		Sample Location								
		Forward			Mid Barrel			Aft		
		Relaxation Modulus, E_r, psi at Time t, Minutes			Relaxation Modulus, E_r, psi at Time t, Minutes			Relaxation Modulus, E_r, psi at Time t, Minutes		
Age mos	Location	0.1	1.0	10.0	0.1	1.0	10.0	0.1	1.0	10.0
12	30°	1633	1285	1102	925	704	604	1687	1312	1107
	210°				-	-	-			
18	75°	1602	1259	1067				1082	826	688
24										
30										
36										
48										
72										
96										
120										
144										

Figure A-33. Effect of Sample Location and Storage Time on Relaxation Modulus of V-45 Insulation, Motor MSEX-2 (1984A)

CHEMICAL PROPERTIES OF V-45 INSULATION
FROM PLUG MOTOR MSEX-II

PLUG MOTOR #	MOTOR LOCATION	AGE MO.	DENSITY	SHORE A	WT% MOISTURE	SWELLING RATIO	GEL FILLER FRACTION	% DOP
MSEX-2	FORWARD END (30 DEG)	12	1.203	65	1.61	1.75	0.845	4.89
MSEX-2	AFT END (30 DEG)	12	1.201	66	1.32	1.73	0.847	5.01
MSEX-2	FORWARD END (75 DEG)	18	1.216	67	1.52	1.72	0.842	5.95
MSEX-2	AFT END (75 DEG)	18	1.218	69	1.63	1.74	0.843	5.74

Figure A-34. Chemical Properties of V-45 Insulation, Plug Motor MSEX-2

Appendix B

Mechanical and Chemical Properties of Laboratory Samples

Appendix B contains detailed tabulations of results of mechanical and chemical testing conducted on laboratory samples. Included are data for samples cast from propellant Lot Combinations 85 through 89A following storage at 8 mo at 135°F, 12 mo at 80°F, and 16 mo at 110°F.

Lot Comb	Storage Time, Month	Storage Temp, °F	0°F σ_m, psi	0°F ϵ_m, %	0°F ϵ_b, %	0°F E_o, psi	0°F SA	40°F σ_m, psi	40°F ϵ_m, %	40°F ϵ_b, %	40°F E_o, psi	40°F SA	77°F σ_m, psi	77°F ϵ_m, %	77°F ϵ_b, %	77°F E_o, psi	77°F SA	110°F σ_m, psi	110°F ϵ_m, %	110°F ϵ_b, %	110°F E_o, psi	110°F SA	150°F* σ_m, psi	150°F* ϵ_m, %	150°F* ϵ_b, %	150°F* E_o, psi	150°F* SA
85A	0																										
	Control	80	164	23	41	1608	45	109	29	48	643	44	90	33	46	396	48	74	34	50	299	45	61	18	19	342	50
	12	80																									
	16	110																									
	8	135	230	16	24	2698	66	172	18	24	1523	65	137	21	26	923	68	117	20	24	791	61	66	17	17	414	64
85B	0												89	35	56	410											
	Control		160	24	43	1432	46	114	27	42	780	44	83	31	44	421	45	74	30	41	382	46	54	26	27	206	46
	12	80	244	21	32	2383	56	178	25	34	1215	53	108	27	38	560	55	99	28	38	503	53	57	20	21	275	-
	16	110	238	17	26	2406	64	176	19	24	1552	66	136	21	25	975	64	119	20	24	867	68	61	18	18	379	63
	8	135	249	16	25	2694	62	175	19	24	1434	64	144	20	25	1038	64	123	21	26	837	61	67	16	17	428	63
86	Control		177	21	41	1801	45	110	28	44	707	47	94	30	40	440	46	80	32	43	344	46	63	20	20	328	52
	8	135	252	16	21	2802	66	179	18	22	1693	65	149	20	25	1076	67	128	20	23	918	66	75	17	17	478	66
86A	0												93	36	55	532											
	Control		212	20	38	2095	52	159	24	36	1132	55	107	29	44	521	53	91	28	42	474	54	61	24	24	269	
	12	80	231	19	29	2478	63	176	21	28	1472	64	123	27	36	657	60	108	27	34	563	64	62	22	23	259	58
	16	110																									
	8	135	258	16	21	2786	71	183	18	22	1565	70	156	19	22	1225	67	130	17	20	1072	70	71	15	15	502	68
87B	0												110	36	51	523											
	Control		197	20	41	1987	55	136	25	42	911	57	107	27	41	591	53	94	28	38	488	55	59	15	15	466	60
	12	80																									
	16	110																									
	8	135	276	15	22	3600	68	191	17	22	1880	68	154	17	19	1324	69	131	16	16	1098	67	65	11	12	624	67
88D	0												95	33	52	503											
	Control		174	24	49	1656	48	114	30	51	586	48	86	33	51	385	50	72	35	53	285	50	60	25	26	246	-
	12	80																									
	16	110																									
	8	135																									
89	0												81	35	56	387											
	Control		176	22	47	1803	51	122	28	46	710	51	96	31	48	448	51	81	33	46	351	53	57	25	26	226	52

* Strain Rate: 0.0074 min^{-1}, all other temperatures at 0.74 min^{-1}

Figure B-1. Comparison of Uniaxial Tensile Properties from the Bulk of Analog Samples of ANB-3066 Propellant

Test Temperature: 77°F
Strain Rate: 100 min^{-1}
Superimposed Pressure: 600 psig

Lot Combo	Storage Time, mo	Storage Temp, °F	σ_m, psi	ε_m, %	ε_b, %	E_o, psi	SA
80A	24	80	369	43	51	1505	55
82E	12	80	372	45	51	1566	52
	16	110	456	39	44	2084	53
83	12	80	362	43	50	1561	54
	16	110	447	36	39	2138	63
84	12	80	402	42	49	1692	62
	16	110	453	31	32	2650	66
	8	135	438	30	31	2518	64
85A	Control		324	47	58	907	44
	8	135	430	31	33	2394	67
85B	Control		317	49	58	1161	44
	12	80	375	43	47	1419	56
	16	110	444	36	38	1939	64
	8	135	456	34	34	2339	64
86	Control		303	49	62	1131	44
	8	135	429	30	32	2467	67
86A	Control		391	44	51	1494	54
	12	80	450	44	46	1865	64
	16	110					
	8	135	461	31	33	2503	68
87B	Control		376	44	54	1467	54
	12	80					
	16	110					
	8	135	469	31	31	2680	64
88D	Control		320	48	60	1228	50
	12	80					
	16	110					
	8	135					
89A	Control		352	51	61	1521	52
	12	80					
	16	110					
	8	135					

Figure B-2. Effect of Storage Time and Temperature on Uniaxial Tensile Properties of ANB-3066 Propellant (High Rate with Superimposed Pressure)

Applied Strain:: 2%

Test Temperature

Lot Comb	Storage Time, Month	Storage Temp, °F	0°F Relaxation Mod., Time 0.1	0°F 1.0	0°F 10.0	40°F Relaxation Mod., Time 0.1	40°F 1.0	40°F 10.0	77°F Relaxation Mod., Time 0.1	77°F 1.0	77°F 10.0	110°F Relaxation Mod., Time 0.1	110°F 1.0	110°F 10.0	150°F Relaxation Mod., Time 0.1	150°F 1.0	150°F 10.0
85A	Control	80	1696	817	479	-	-	-	457	286	222	-	-	-	339	256	196
	12	80															
	16	110															
	8	135	2973	1778	1223	-	-	-	1020	735	594	-	-	-	645	507	408
85B	Control	80	1646	772	448	-	-	-	438	277	216	-	-	-	245	182	143
	12	80	1927	1020	642	-	-	-	490	322	253	-	-	-	321	243	192
	16	110	3167	1846	1248	-	-	-	958	675	539	-	-	-	621	492	401
	8	135	3177	1886	1284	-	-	-	1076	750	603	-	-	-	685	538	439
86	Control	80	1652	800	472				450	279	215	413	284	222	409	304	235
	8	135	3603	2184	1540	-	-	-	1170	838	682	-	-	-	677	533	438
86A	Control	80	2245	1204	753	-	-	-	600	379	292	-	-	-	301	229	182
	12	80	2933	1660	1077	-	-	-	845	564	446	-	-	-	448	342	275
	16	110															
	8	135	3462	2158	1521	-	-	-	1265	928	760	-	-	-	956	734	606
87B	Control	-	2061	1076	698	-	-	-	539	349	271	379	275	220	-	-	-
	12	80															
	16	110															
	8	135	4178	2619	1868	-	-	-	1641	1185	963	-	-	-	1186	930	768
88D	Control		1646	746	459	-	-	-	352	220	171	-	-	-	224	164	127
	12	80															
	16	110															
	8	135															
89	Control		2014	972	593	-	-	-	441	267	202	-	-	-	252	187	144

* Applied Strain 0.5%

Figure B-3. Effect of Test Temperature on Relaxation Modulus for ANB-3066 Propellant: Different Lot Combinations

Lot Comb	Time, Month	Temp, °F	0.1 in. from Bore σ_m, psi	ϵ_m, %	ϵ_b, %	E_o, psi	0.2 in. from Bore σ_m, psi	ϵ_m, %	ϵ_b, %	E_o, psi	0.5 in. from Bore σ_m, psi	ϵ_m, %	ϵ_b, %	E_o, psi	1.0 in. from Bore σ_m, psi	ϵ_m, %	ϵ_b, %	E_o, psi	2.0 in. from Bore σ_m, psi	ϵ_m, %	ϵ_b, %	E_o, psi
85A	Control	80	107	24	34	670	100	25	38	595	97	27	42	525	94	29	40	450	93	31	44	427
	12																					
	16	110																				
	8	135	178	10	11	2201	177	11	13	2166	160	14	16	1476	132	21	29	900	132	19	24	946
85B	Control	80	98	25	34	579	95	24	35	552	82	28	41	441	77	29	44	389	75	32	45	326
	12	80	129	18	28	1002	129	19	28	950	132	20	26	923	122	24	31	754	101	27	38	541
	16	110	159	13	15	1682	157	13	17	1674	147	15	18	1370	113	25	35	691	120	22	28	793
	8	135	194	10	11	2712	190	10	12	2580	150	16	20	1340	133	21	30	1023	132	19	25	956
86	Control	80	116	24	32	758	107	24	32	657	97	27	38	537	94	29	40	488	92	31	43	443
	8	135	186	10	10	2536	182	10	11	2365	161	14	16	1514	134	20	27	937	142	19	24	996
86A	Control	80	128	19	29	1332	120	19	29	1120	109	22	31	904	99	25	40	699	98	26	38	580
	12	80	137	19	27	1065	137	19	25	1087	147	17	23	1233	139	20	25	1094	122	23	32	795
	16	110																				
	8	135	196	10	11	2666	190	10	11	2680	154	16	18	1388	139	20	25	1069	149	19	22	1171
87B	Control		138	17	27	1247	132	18	27	1166	115	20	34	905	98	25	38	631	99	25	37	623
	12	80																				
	16	110																				
	8	135	203	8	8	3283	201	8	10	3154	166	15	18	1670	150	19	24	1247	156	16	19	1502
88D	Control		106	21	36	796	100	22	36	723	90	26	41	553	86	26	40	495	88	27	45	437
	12	80																				
	16	110																				
	8	135																				
89	Control		99	20	37	900	100	24	37	828	96	24	37	746	91	26	41	614	90	27	43	482

Figure B-4. Comparison of Uniaxial Tensile Gradient from the Simulated Bore Surface of Analog Samples of ANB-3066 Propellant (Sealed Samples)

Test Temp: 77°F
Applied Strain: 2.0%

Lot Comb	Storage Time, Month	Storage Temp, °F	0.1 in. from Bond Relaxation Mod., Time 0.1	1.0	10.0	0.2 in. from Bond Relaxation Mod., Time 0.1	1.0	10.0	0.5 in. from Bond Relaxation Mod., Time 0.1	1.0	10.0	1.0 in. from Bond Relaxation Mod., Time 0.1	1.0	10.0	2.0 in. from Bond Relaxation Mod., Time 0.1	1.0	10.0
85A	Control	80	2686	1778	1363	1360	839	638	751	469	375	783	490	381	775	489	382
	8	135	1046	706	550	2530	1768	1382	1295	846	662	863	519	401	1042	672	526
85B	Control	80	929	644	522	940	576	442	590	368	287	649	405	316	658	411	320
	12	80	1383	975	762	1545	1003	771	1102	708	562	756	471	377	590	385	313
	16	110	708	517	418	2061	1426	1119	1832	1282	1028	960	612	482	1032	680	540*
	8	135	962	650	522	2414	1759	1386	879	559	430	904	593	466	1116	758	608
86	Control	80	1380	947	726	1271	777	575	900	539	422	779	476	360	826	507	392
	8	135	1408	997	797	2841	2020	1572	1288	842	668	1243	788	617	1444	982	790
86A	Control	80	1268	846	679	1321	815	628	735	455	357	809	507	392	809	504	387*
	12	80	2536	1767	1400	2130	1379	1168	1494	973	776	1280	815	656	982	645	515
	16	110															
	8	135	1608	1140	911	2424	1736	1374	1218	764	594	1330	888	702	-	-	-
87B	Control	80	2750	1931	1524	2060	1312	999	1185	728	549	1200	744	574	1094	677	515
	12	80															
	16	110															
	8	135	2119	1523	1248	3883	2752	2232	1952	1234	951	1972	1303	1040	2298	1592	1278
88D	Control		2265	1505	1168	1152	727	574	628	390	314	578	362	291	625	388	302*
	12	80															
	16	110															
	8	135															
89	Control		2358	1554	1185	1495	892	652	985	593	455	894	535	410	885	526	402*

* 1.5 in. from bond interface.

Figure B-5. Comparison of Mini Stress Relaxation Modulus from the Simulated Bond Surface of Analog Samples of ANB-3066 Propellant

	Standard	Mini
Type Specimen →	Standard	Mini
Test Temperature, °F →	77	77
Crosshead Rate, in./min →	1.0	0.5

Lot Combo	Time, mo	Temp, °F	Standard Stress, psi	Standard Time, min	Standard Type Failure, % APL	Standard Type Failure, % CL	Mini Stress, psi	Mini Time min	Mini Type Failure, % APL	Mini Type Failure, % CL
85A	0									
	Control		93	0.13	90	10	96	0.16	100	
	8	135	74	0.38	95	5	64	0.49	95	5
85B	0									
	Control		85	0.30	85	15	72	0.31	85	15
	12	80	78	0.21	60	40	71	0.26	65	35
	16	110	59	0.23	50	50	64	0.34	50	50
	8	135	63	0.24	80	20	58	0.27	65	35
86	0									
	Control		94	0.15	90	10	80	0.17	95	5
	8	135	72	0.25	50	50	62	0.20	60	40
86A	0									
	Control		99	0.14	100		100	0.08	100	
	12	80	107	0.10	97	3	84	0.13	96	4
	16	110								
	8	135	71	0.25	90	10	80	0.52	80	20

Figure B-6. Effect of Storage Temperature and Time on Tensile Strength of Propellant-Liner-Insulation Bond System, Sheet 1 of 2

Type Specimen →			Standard				Mini			
Test Temperature, °F →			77				77			
Crosshead Rate, in./min →			1.0				0.5			
					Type Failure, %				Type Failure, %	
Lot Combo	Time, mo	Temp, °F	Stress, psi	Time, min	APL	CL	Stress, psi	Time min	APL	CL
87B	0 Control		86	0.18	60	40	86	0.23	50	50
	12	80								
	16	110								
	8	135	88	0.07	70	30	88	0.04	70	30
88D	0 Control		84	0.26	100		82	0.36	100	
	12	80								
	16	110								
	8	135								
89	0 Control									

Figure B-6. Effect of Storage Temperature and Time on Tensile Strength of Propellant-Liner-Insulation Bond System, Sheet 2 of 2

Test Temperatue: 77°F
Crosshead Rate: 200 in./min
Superimposed Pressure: 600 psig

Lot Combo	Storage Time, mo	Storage Temp, °F	Stress, psi	Time to Fail, sec	CP	CPI	Type Failure, % APL	CLI	CL	ALI	F
85A	Control		220	0.102			10		90		
	8	135	243	0.122			30		70		
85B	Control		241	0.120			70		30		
	12	80	208	0.105			50		50		
	16	110	172	0.055			50		50		
86	Control		250	0.113			50		50		
	8	135	282	0.107			100				
86A	Control		272	0.140			60		40		
	12	80	222	0.084			30		70		
	16	110									
	8	135	170	0.112			25		75		
87B	Control		253	0.160			50		40	10	
	12	80									
	16	110									
	8	135	217	0.120			30		70		
88D	Control		253	0.114			60		40		
	12	80									
	16	110									
	8	135									
89	Control										

Figure B-7. Effect of Storage Conditions on Bond Shear Strength of Propellant-Liner-Insulation System (ANB-3066/SD-851-2/V-45)

Lot Combo	Storage Time, Mos.	Storage Temp, °F	Stress, psi	Time, Min.	Type Failure, % APL	CP	CLI	CL	F	Stress, psi	Time, Min.	Type Failure, % APL	CP	CLI	CL	F	Stress, psi	Time, Min.	Type Failure, % APL	CP	CLI	CL	F	Stress, psi	Time, Min.	Type Failure, % APL	CP	CLI	CL	F
85A	Control	80	40	667	50			50		35	861	50			50		30	1610	20	40		40		25	13217	50			50	
	8	135	50	15						40	919						35	4040						30	53184		95		5	
85B	Control	80	50	3.0					100	45	10.4	90			10		30	549	50			50		25	8420	60			40	
	12	80	55	8.0	40			60		45	1028	70			30		40	6464	70			30		35	14661	50	50			
	16	110	40	6.8	50			50		35	62	30			70		30	954	40			60		25	17670	40			60	
	8	135	40	28	60			40		35	305	25			75		30	1192	20			80		28	2257	20			80	
86	Control	80	45	230	90			10		40	497	90			10		35	818	90			10		30	1990	70			30	
	8	135	40	44	70			30		35	1067	60			40		30	2691	70			30		27.5	182531					
86A	Control	80	55	11.3	60			40		50	83	90			10		45	137	75			25		40	313	60			40	
	12	80	50	96	40			60		45	111	60			40		40	678	60			40		35	2301	50			50	
	16	110																												
	8	135	45	6.9	50			50		40	93				100		35	3068				100		30	6181				100	
87B	Control	80	50	107	40			60		45	1032	40			60		40	4153	30			70		35	112531					
	12	80																												
	16	110																												
	8	135	45	9.1	50			50		40	1090	70			30		35	111	40			60		30	3653	40			60	
88D	Control		50	22	60			40		45	136	25			75		40	282	50			50		35	950	40			60	
	12	80																												
	16	110																												
	8	135																												
89	Control																													

* Test Discontinued

Figure B-8. Comparison of Constant Load Bond Tensile Results from Analog Samples of ANB-3066 Propellant

Applied Strain: 2%

Lot Comb	Storage Time, Month	Storage Temp, °F	Test Temperature 0°F Relaxation Mod., Time 0.1	0°F 1.0	0°F 10.0	77°F Relaxation Mod., Time 0.1	77°F 1.0	77°F 10.0	77°F* Relaxation Mod., Time 0.1	77°F* 1.0	77°F* 10.0	150°F Relaxation Mod., Time 0.1	150°F 1.0	150°F 10.0
85A	Control	80	3885	1668	1180	-	-	-	-	-	-	737	616	551
	8	135	6157	3964	3210	1691	1357	1190	-	-	-	1274	1070	949
85B	Control	80	6997	2749	1896	1071	847	729	-	-	-	695	582	527
	12	80	7022	3390	2493	1568	1253	1116	-	-	-	928	783	704
	16	110	12223	5016	3372	1840	1503	1314	-	-	-	1108	930	814
	8	135	15006	5196	3187	1846	1533	1344	-	-	-	1048	880	800
86	Control	80	5706	2331	1646	1268	990	851	-	-	-	767	612	541
	8	135	12902	4928	3126	2019	1656	1440	-	-	-	1513	1256	1130
86A	Control	80	6536	2899	2081	1490	1215	1061	-	-	-	907	762	680
	12	80	5532	2477	1853	2008	1656	1434	-	-	-	790	652	574
	16	110												
	8	135	6196	2952	2188	1779	1445	1267	-	-	-	910	701	621
87B	Control	80	8763	3618	2445	1351	1088	967	-	-	-	904	774	681
	12	80												
	16	110												
	8	135	11425	4673	2789	2170	1774	1561	-	-	-	1352	1120	988
88D	Control		10746	4287	2826	1552	1294	1158	-	-	-	1007	857	774
	12	80												
	16	110												
	8	135												
89	Control		6218	3166	2422	1459	1162	1040	-	-	-	906	776	712

* Applied Strain: 0.5%

Figure B-9. Effect of Test Temperature on Relaxation Modulus for Insulation from Analog Samples of ANB-3066 Propellant

LOT COMBO	TIME MONTH	TEMP F	DISTANCE INCHES	INITIAL WEIGHT	917 IW	970 IW	995 IW	1725 WN	970/ 2850
85A #370	0	77	0.0	0.9845	0.135	0.188		0.036	1.267
			0.1	1.0557	0.120	0.181		0.034	1.209
			0.2	1.0865	0.119	0.179		0.034	1.176
			0.3	1.0049	0.123	0.182		0.036	1.188
			0.5	1.0404	0.122	0.191		0.038	1.228
			2.0	0.9520	0.127	0.189		0.037	1.259
85A #3[illegible]	[illegible]	[illegible]	0.0	1.0740	0.073	0.095		0.037	0.836
			0.1	1.0740	0.076	0.101		0.040	0.832
			0.2	1.0618	0.082	0.105		0.047	0.965
			0.3	1.0420	0.067	0.097		0.038	0.894
			0.5	1.0929	0.102	0.155		0.044	1.018
			2.0	1.0587	0.092	0.132		0.042	0.966
85B #3[illegible]	[illegible]	[illegible]	0.0	1.0720	0.149	0.230		0.054	1.199
			0.1	1.0787	0.138	0.211		0.051	1.188
			0.2	1.0462	0.141	0.218		0.054	1.194
			0.3	1.0181	0.132	0.189		0.050	1.011
			0.5	1.0599	0.138	0.199		0.050	1.077
			2.0	1.0740	0.152	0.234		0.055	1.201
85B #38[illegible]	[illegible]	135	0.0	1.0128	0.074	0.100		0.025	0.981
			0.1	1.0688	0.066	0.094		0.025	1.000
			0.2	1.0528	0.058	0.091		0.026	1.011
			0.3	1.0689	0.057	0.093		0.024	0.990
			0.5	1.0450	0.099	0.158		0.037	1.138
			2.0	1.0238	0.087	0.131		0.032	1.055
85B #389	12	80	0.0	1.0572		0.171		0.034	1.040
			0.1	1.0692		0.155		0.032	1.012
			0.2	0.9936		0.154		0.035	1.027
			0.3	1.0108		0.151		0.032	1.013
			0.5	1.0307		0.147		0.033	1.007
			2.0	1.0550		0.159		0.035	1.012
85B #387	16	110	0.0	1.0809	0.092	0.128	0.068	0.035	1.045
			0.1	1.0977	0.086	0.122	0.056	0.076	0.950
			0.2	1.0423	0.091	0.130	0.063	0.077	1.000
			0.3	1.0722	0.083	0.118	0.055	0.076	0.962
			0.5	1.0572	0.094	0.131	0.065	0.079	1.037
			2.0	1.0629	0.115	0.159	0.073	0.082	1.030
86 #346	0	[illegible]	0.0	1.2320	0.127	0.186		0.042	1.134
			0.1	1.1833	0.139	0.210		0.046	1.143
			0.2	1.0487	0.126	0.193		0.042	1.141
			0.3	1.0671	0.118	0.184		0.041	1.140
			0.5	1.1054	0.126	0.194		0.043	1.120
			2.0	1.1735	0.132	0.201		0.043	1.151

Figure B-10. Transmission Spectra of Chloroform Extractables Normalized to Initial Weight of 1.0 g : Gradient from Bore Surface of Analog Samples, Sheet 1 of 3

TRANSMISSION SPECTRA OF CHLOROFORM EXTRACTABLES
NORMALIZED TO INITIAL WEIGHT OF 1.0 g
GRADIENT FROM BORE SURFACE OF ANALOG SAMPLES

LOT COMBO	TIME MONTH	TEMP F	DISTANCE INCHES	INITIAL WEIGHT	917 IW	970 IW	995 IW	1725 WN	970/2850
86 #383	8	135	0.0	1.0729	0.059	0.080		0.031	0.748
			0.1	1.0425	0.053	0.084		0.033	0.793
			0.2	1.0944	0.049	0.082		0.031	0.804
			0.3	1.0547	0.053	0.086		0.033	0.798
			0.5	1.0905	0.083	0.138		0.040	0.962
			2.0	1.0954	0.069	0.121		0.041	0.943
86A #401	[illegible]	[illegible]	0.0	1.0141	0.116	0.170		0.056	1.162
			0.1	1.0175	0.095	0.152		0.041	1.157
			0.2	1.0839	0.096	0.151		0.042	1.155
			0.3	1.0026	0.087	0.152		0.039	1.160
			0.5	1.0627	0.088	0.151		0.039	1.127
			2.0	1.0008	0.087	0.149		0.042	1.183
86A #400	[illegible]	135	0.0	1.0955	0.059	0.079		0.026	0.860
			0.1	1.0935	0.051	0.075		0.024	0.882
			0.2	1.0576	0.054	0.078		0.026	0.828
			0.3	1.0174	0.050	0.077		0.024	0.796
			0.5	1.0767	0.074	0.115		0.029	0.984
			2.0	1.0648	0.068	0.101		0.029	0.956
86A #402	16	80	0.0	1.0308	0.117	0.171	0.077	0.054	1.086
			0.1	1.0248	0.101	0.140	0.061	0.043	1.014
			0.2	0.9948	0.099	0.143	0.063	0.045	1.000
			0.3	1.0551	0.100	0.145	0.067	0.046	0.994
			0.5	0.9581	0.095	0.141	0.067	0.049	0.964
			2.0	0.9273	0.114	0.170	0.079	0.054	1.060
87B #415	0	80	0.0	1.0842	0.101	0.148		0.037	1.176
			0.1	1.0710	0.099	0.148		0.035	1.153
			0.2	0.9839	0.096	0.144		0.035	1.174
			0.3	1.0056	0.096	0.147		0.038	1.165
			0.5	1.0440	0.106	0.156		0.036	1.156
			2.0	1.0204	0.103	0.157		0.037	1.159
87B #413	8	135	0.0	1.0252	0.071	0.092	0.056	0.050	0.770
			0.1	0.9643	0.068	0.088	0.051	0.040	0.773
			0.2	1.0619	0.057	0.078	0.040	0.035	0.692
			0.3	1.0547	0.064	0.087	0.047	0.036	0.736
			0.5	1.0693	0.095	0.135	0.065	0.045	0.917
			2.0	1.0499	0.085	0.115	0.059	0.042	0.864
88D #420	[illegible]	[illegible]	0.0	1.0416	0.124	0.176	0.088	0.046	1.204
			0.1	1.0576	0.108	0.155	0.068	0.044	1.093
			0.2	1.0514	0.113	0.160	0.073	0.045	1.159
			0.3	1.0731	0.111	0.161	0.069	0.043	1.068
			0.5	1.0424	0.125	0.178	0.082	0.048	1.170
			2.0	1.0066	0.123	0.177	0.077	0.049	1.134

Figure B-10. Transmission Spectra of Chloroform Extractables Normalized to Initial Weight of 1.0 g : Gradient from Bore Surface of Analog Samples, Sheet 2 of 3

TRANSMISSION SPECTRA OF CHLOROFORM EXTRACTABLES
NORMALIZED TO INITIAL WEIGHT OF 1.0 g
GRADIENT FROM BORE SURFACE OF ANALOG SAMPLES

LOT COMBO	TIME MONTH	TEMP F	DISTANCE INCHES	INITIAL WEIGHT	917 IW	970 IW	995 IW	1725 WN	970/ 2850
89A	0	77	0.0	1.0737	0.133	0.192	0.080	0.060	1.079
#500			0.1	1.0411	0.131	0.195	0.081	0.062	1.046
			0.2	1.0654	0.139	0.206	0.086	0.069	1.043
			0.3	1.0517	0.121	0.182	0.073	0.052	1.055
			0.5	1.0340	0.174	0.258	0.117	0.097	1.085
			2.0	0.9950	0.130	0.193	0.078	0.057	1.110

Figure B-10. Transmission Spectra of Chloroform Extractables Normalized to Initial Weight of 1.0 g : Gradient from Bore Surface of Analog Samples, Sheet 3 of 3

PEAK HEIGHTS IN TRANSMISSION SPECTRA OF CHLOROFORM EXTRACTABLES
NORMALIZED TO INITIAL WEIGHT OF 1.0 g
GRADIENT FROM BONDLINE INTERFACE OF ANALOG SAMPLES

ID#	TIME MONTH	TEMP F	DISTANCE INCHES	INITIAL WEIGHT	917 IW	970 WN	995 IW	1295 WN	970/2850
85A #370	0	[illegible]	0.0	1.0403		0.105		0.030	1.239
			0.1	1.0783		0.181		0.037	1.413
			0.2	0.9391		0.179		0.027	1.282
			0.3	1.1044		0.179		0.027	1.179
			0.5	1.0539		0.166		0.009	1.087
			2.0	1.0160		0.163		0.010	1.114
85A #[illegible]	8	135	0.0	1.0312		0.112		0.041	1.009
			0.1	1.0564		0.128		0.043	1.107
			0.2	1.0462		0.097		0.035	1.086
			0.3	1.0452		0.180		0.045	1.182
			0.5	1.0762					
			2.0	1.0434		0.147		0.027	1.109
85B #386	0	[illegible]	0.0	1.0207		0.143		0.047	0.986
			0.1	1.0765		0.207		0.045	1.205
			0.2	1.0462		0.230		0.050	1.176
			0.3	1.0164		0.187		0.022	1.000
			0.5	1.0942		0.224		0.038	1.184
			2.0	1.0340		0.225		0.040	1.165
85B #3[illegible]	8	135	0.0	1.0769		0.143		0.049	0.962
			0.1	1.0345		0.118		0.038	1.043
			0.2	0.9889		0.093		0.040	0.968
			0.3	1.0022		0.098		0.034	1.043
			0.5	0.9608		0.172		0.030	1.187
			2.0	0.8816					
85B #389	12	80	0.0	1.0357		0.122		0.048	0.920
			0.1	1.0575		0.145		0.039	1.027
			0.2	1.0285		0.150		0.038	1.055
			0.3	0.9621		0.151		0.032	1.082
			0.5	0.9946		0.144		0.023	1.014
			2.0	0.9806		0.155		0.022	1.020
85B #[illegible]	16	110	0.0	1.0522	0.133	0.172	0.086	0.050	1.090
			0.1	1.0669	0.082	0.117	0.054	0.035	1.068
			0.2	1.0626	0.094	0.131	0.062	0.039	1.112
			0.3	1.0523	0.086	0.122	0.058	0.034	1.058
			0.5	1.0712	0.093	0.134	0.062	0.034	1.099
			2.0	1.0194	0.106	0.152	0.069	0.025	1.131
[illegible] #[illegible]	0	[illegible]	0.0	1.1562		0.106		0.037	1.220
			0.1	1.1131		0.178		0.036	1.200
			0.2	1.0154		0.180		0.024	1.181
			0.3	1.0213		0.195		0.026	1.178
			0.5	1.1071		0.201		0.027	1.162
			2.0	1.0851		0.199		0.029	1.161

Figure B-11. Peak Heights in Transmission Spectra of Chloroform Extractables Normalized to Initial Weight of 1.0 g : Gradient from Bondline Interface of Analog Samples, Sheet 1 of 3

PEAK HEIGHTS IN TRANSMISSION SPECTRA OF CHLOROFORM EXTRACTABLES
NORMALIZED TO INITIAL WEIGHT OF 1.0 g
GRADIENT FROM BONDLINE INTERFACE OF ANALOG SAMPLES

ID#	TIME MONTH	TEMP F	DISTANCE INCHES	INITIAL WEIGHT	917 IW	970 WN	995 IW	1295 WN	970/ 2850
86	8	135	0.0	1.0658		0.117		0.048	0.812
#383			0.1	1.0865		0.094		0.039	0.836
			0.2	1.0775		0.085		0.038	0.814
			0.3	1.0881		0.094		0.037	0.823
			0.5	1.0773		0.157		0.042	1.012
			2.0	1.0888		0.136		0.028	0.961
86A	0	[illegible]	0.0	0.9099		0.158		0.014	1.125
#40[illegible]			0.1	1.0085		0.136		0.019	1.142
			0.2	1.0465		0.136		0.017	1.092
			0.3	1.0297		0.142		0.016	1.123
			0.5	1.0495		0.142		0.014	1.088
			2.0	1.0314		0.146		0.017	1.135
[illegible]	[illegible]	[illegible]	0.0	1.0557		0.094		0.044	0.861
#[illegible]			0.1	1.0371		0.090		0.037	0.949
			0.2	1.0187		0.077		0.030	0.857
			0.3	1.0666		0.087		0.031	0.930
			0.5	1.0874		0.136		0.031	1.035
			2.0	1.0639		0.117		0.021	1.000
86A	[illegible]	[illegible]	0.0	0.9869	0.068	0.094	0.052	0.059	0.802
#40[illegible]			0.1	1.0366	0.095	0.137	0.061	0.046	1.000
			0.2	1.0604	0.101	0.139	0.062	0.041	0.987
			0.3	0.9768	0.102	0.144	0.067	0.042	0.993
			0.5	0.9611	0.097	0.137	0.060	0.033	0.936
			2.0	1.0077	0.117	0.169	0.076	0.036	1.006
87B	0	[illegible]	0.0	1.0684		0.117		0.041	1.068
#415			0.1	1.0631		0.134		0.025	1.224
			0.2	1.0505		0.143		0.019	1.163
			0.3	1.0762		0.144		0.017	1.192
			0.5	1.0847		0.151		0.018	1.197
			2.0	1.0724		0.151		0.021	1.157
87B	8	135	0.0	1.0369	0.092	0.129	0.067	0.057	0.802
#413			0.1	1.0743	0.073	0.106	0.054	0.046	0.797
			0.2	1.0523	0.059	0.085	0.045	0.040	0.706
			0.3	1.0236	0.071	0.095	0.052	0.043	0.789
			0.5	1.0664	0.109	0.151	0.070	0.040	0.947
			2.0	1.0038	0.092	0.124	0.060	0.026	0.861
88D	0	[illegible]	0.0	1.0518	0.063	0.087	0.048	0.034	1.227
#420			0.1	1.0316	0.105	0.150	0.071	0.032	1.240
			0.2	1.0449	0.112	0.160	0.072	0.030	1.160
			0.3	1.0786	0.109	0.159	0.069	0.025	1.103
			0.5	1.0512	0.120	0.176	0.076	0.027	1.108
			2.0	1.0312	0.115	0.167	0.077	0.028	1.162

Figure B-11. Peak Heights in Transmission Spectra of Chloroform Extractables Normalized to Initial Weight of 1.0 g : Gradient from Bondline Interface of Analog Samples, Sheet 2 of 3

PEAK HEIGHTS IN TRANSMISSION SPECTRA OF CHLOROFORM EXTRACTABLES
NORMALIZED TO INITIAL WEIGHT OF 1.0 g
GRADIENT FROM BONDLINE INTERFACE OF ANALOG SAMPLES

ID#	TIME MONTH	TEMP F	DISTANCE INCHES	INITIAL WEIGHT	917 IW	970 WN	995 IW	1295 WN	970/ 2850
89A	0	77	0.0	1.0739	0.062	0.092	0.038	0.028	1.000
#500			0.1	1.0398	0.111	0.169	0.070	0.034	1.121
			0.2	1.0150	0.116	0.177	0.075	0.032	1.065
			0.3	1.0365	0.122	0.182	0.076	0.029	1.080
			0.5	1.0652	0.127	0.190	0.079	0.028	1.098
			2.0	1.0179	0.127	0.190	0.079	0.028	1.116

Figure B-11. Peak Heights in Transmission Spectra of Chloroform Extractables Normalized to Initial Weight of 1.0 g : Gradient from Bondline Interface of Analog Samples, Sheet 3 of 3

CHEMICAL PROPERTIES OF SD-851-2 LINER
ANALOG SAMPLES FROM LOT COMBINATIONS 75 TO 89A

TIME/ TEMP	LOT COMBO	Se/So	GEL-FILLER FRACTION*	TIME/ TEMP	LOT COMBO	Se/So	GEL-FILLER FRACTION*
0/77	LC 75	1.86			LC 78	2.12	0.566
	LC 76	1.90	0.621		LC 79	2.01	
	LC 77	2.02	0.667		LC 80A	1.95	0.567
	LC 78	1.97	0.671		LC 81A	1.98	0.591
	LC 79	1.88	0.705		LC 82E	1.99	0.576
	LC 80A	1.78	0.693		LC 83	2.01	0.545
	LC 81A	1.81	0.712		LC 84	2.00	0.586
	LC 82E	1.86	0.681		LC 85B	2.02	0.580
	LC 83	1.85					
	LC 84	1.92					
	LC 85A	1.84	0.696				
	LC 85B	1.89	0.670				
	LC 86	1.87	0.730				
	LC 86A	1.79	0.694				
	LC 87B	1.82					
	LC 88D	1.71	0.737				
	LC 89A	1.88	0.708				
8/135	LC 75	2.17					
	LC 76	2.14	0.583				
	[illegible]	2.13	0.572				
	LC 78	2.19	0.592				
	LC 79	2.15	0.582				
	LC 80A	2.03					
	LC 81A	1.90	0.608				
	LC 82E	1.94	0.626				
	LC [illegible]	2.05	0.598				
	LC 84	2.04	0.597				
	LC 85A	1.96	0.587				
	LC 85B	2.01	0.571				
	LC 86	1.86	0.591				
	LC 86A	1.98	0.593				
	LC 87B	1.95	0.591				
12/80	[illegible]	1.73	0.692				
	LC 77	1.89	0.694				
	LC 78	1.85	0.708				
	LC 79	1.79	0.660				
	LC 80A	1.84	0.674				
	LC 81A	1.78	0.675				
	LC 82F	1.86	0.679				
	LC 83	1.86	0.653				
	LC 84	1.89	0.648				
	LC 85B	1.90	0.611				
	LC 86A	1.82	0.644				
16/110	LC 75	1.95					
	LC 76	2.01	0.598				
	LC 77	1.92	0.594				

* Gel Filler Fraction Corrected for Variations in Liner Thickness

Figure B-12. Chemical Properties of SD-851-2 Liner: Analog Samples from Lot Combinations 75 to 89A

TIME TEMP	LOT COMBO	DENSITY	SHORE A METAL	SHORE A 0.25" PROP.	% H2O	Se/So	GEL	DOP
0/77	LC 75	1.216	65	51	1.89	1.75	0.850	4.40
	LC 76	1.215	62	51	1.90	1.74	0.847	5.45
	LC 77	1.217	63	52	1.88	1.76	0.845	5.00
	LC 78	1.221	61	49	1.91	1.79	0.839	6.40
	LC 79	1.205	61	54	1.83	1.81	0.834	5.05
	LC 80A	1.211	62	54	1.75	1.72	0.837	4.80
	LC 81A	1.216	60	53		1.78	0.850	5.49
	LC 82E	1.210	65	57		1.75	0.843	4.79
	LC 83	1.180		58	1.67	1.77	0.842	4.72
	LC 84	1.191	64	52	1.69	1.88	0.835	4.36
	LC 85A	1.208	61	51	1.86	1.79	0.839	4.98
	LC 85B	1.209	64	54	1.38	1.69	0.852	4.54
	LC 86	1.212	64	55	1.91	1.72	0.848	5.95
	LC 86A	1.195	64	58	1.78	1.71	0.846	4.57
	LC 87B	1.207	65	56	1.73	1.71	0.846	5.41
	LC 88D	1.220	71	63	2.04	1.61	0.861	5.56
	LC 89A		68	55		1.73	0.851	4.52
8/1[illegible]	LC 75	1.226	71		1.70	1.68	0.894	1.40
	LC 76	1.228	70	57	1.84	1.65	0.900	1.60
	LC 77	1.227	83	67	1.51	1.67	0.904	1.10
	LC 78	1.232	71	66	1.70	1.65	0.908	1.50
	LC 79	1.224	75	68	1.65	1.73	0.891	1.50
	LC 80A	1.242	71	51		1.76	0.928	2.65
	LC 81A	1.230	72	59	1.68	1.71	0.891	1.77
	LC 82E	1.222	70	58	1.71	1.65	0.890	1.65
	LC 83	1.220	68	58	1.61	1.68	0.892	2.63
	LC 84	1.204	61	49	1.54	1.77	0.887	1.73
	LC 85A	1.215	66	55	1.65	1.67	0.895	1.92
	LC 85B	1.216	70	65	1.78	1.65	0.899	1.83
	LC 86	1.213	68	63	1.65	1.69	0.896	1.61
	LC 86A	1.221	71	59	1.20	1.69	0.898	1.20
	LC 87B		71	58		1.65	0.894	0.91
12/80	LC 76	1.225	74	59	2.07	1.76	0.865	3.25
	LC 77	1.218	64	56	2.00	1.79	0.866	3.30
	LC 78	1.218	67	61	2.04	1.76	0.857	3.80
	LC 79	1.207	64	55	1.83	1.80	0.844	3.27
	LC 80A	1.220		56	1.95	1.86	0.847	3.09
	LC 81A	1.220	62	52	1.92	1.71	0.854	3.54
	LC 82E	1.211	60	53	1.99	1.75	0.863	3.04
	LC 83	1.211	63	55	1.74	1.70	0.852	3.31
	LC 84		60	55	1.75	1.80	0.845	3.78
	LC 85B	1.215	69	59	1.96	1.69	0.856	3.25
	LC 86A		64	58	1.93	1.72	0.857	2.98
16/110	LC 75	1.230	71	62	1.65	1.79	0.892	1.50
	LC 76	1.228	68	57	1.70	1.70	0.899	1.50
	LC 77	1.224	72	64	1.75	1.79	0.885	1.60
	LC 78	1.218	71	57	1.78	1.80	0.908	1.49
	LC 79	1.212	62	54	1.67	1.78	0.586	4.54

Figure B-13. Chemical Properties of V-45 Insulation: Analog Samples from Lot Combinations 75 to 89A, Sheet 1 of 2

CHEMICAL PROPERTIES OF V-45 INSULATION
ANALOG SAMPLES FROM LOT COMBINATIONS 75 TO 89A

TIME TEMP	LOT COMBO	DENSITY	SHORE A METAL	SHORE A 0.25" PROP.	% H2O	Se/So	GEL	DOP
16/110	LC 80A	1.219	66	47	1.92	1.81	0.884	1.26
	LC 81A	1.221	70	55	2.02	1.72	0.887	1.31
	LC 82E	1.214	66	54	2.09	1.68	0.882	1.87
	LC 83	1.215	68	60	1.87	1.67	0.884	1.77
	LC 84	1.198	69	58	1.66	1.73	0.894	1.93
	LC 85B	1.231	73	59	1.71	1.66	0.899	1.75

Figure B-13. Chemical Properties of V-45 Insulation: Analog Samples from Lot Combinations 75 to 89A, Sheet 2 of 2

Appendix C

Component Test Data

Blend 373

GG TYPE	SERIAL NO	BLEND	GG AGE MO	TEST DATE	AGING TEMP F	GG TEST TYPE	VIBRATION	IGNITION DELAY SEC	IGNITION TIME SEC	BURN DURATION SEC	MEOP PSIA	COMMENTS
BAA	0001024.	0373.	031.00	6-01-68	110.00	AGING	NONE	0.0360	0.1320	101.30	2040.00	
BAA	0001026.	0373.	036.00	7-03-68	080.00	AGING	DFIRE	0.0510	0.1470	102.70	1900.00	
BAA	0001027.	0373.	036.00	7-03-68	080.00	AGING	NONE	0.0350	0.1620	098.50	1923.00	
BAA	0001025.	0373.	036.00	12-01-68	110.00	AGING	NONE	0.0400	0.1600	097.20	2050.00	
BAA	0001028.	0373.	048.00		080.00	AGING	DFIRE	0.0330	0.1300	097.20	2030.00	
BAA	0001031.	0373.	048.00		080.00	AGING	NONE	0.0310	0.1580	101.60	1826.00	
BAA	0000374.	0373.	018.00	6-01-67	110.00	AGING	NONE	0.0250	0.1170	093.20	2063.00	
BAA	0001017.	0373.	005.00	3-01-66	135.00	AGING	NONE	0.0350	0.1690	105.70	1870.00	
BAA	0001018.	0373.	006.00	6-01-66	135.00	AGING	NONE	0.0340	0.1630	101.70	1860.00	
BAA	0001019.	0373.	009.00	9-01-66	135.00	AGING	NONE	0.0290	0.1450	097.80	2030.00	
BAA	0001020.	0373.	012.00	12-01-66	135.00	AGING	NONE	0.0360	0.1540	098.00	1930.00	
BAA	0001021.	0373.	006.00	6-01-66	110.00	AGING	NONE	0.0310	0.1580	102.50	1950.00	
BAA	0001022.	0373.	012.00	12-01-66	110.00	AGING	NONE	0.0310	0.1380	101.00	1940.00	
BAA	0001041.	0373.	014.00	7-03-66	080.00	AGING	DFIRE	0.0360	0.1550	098.20	1820.00	
BAA	0001042.	0373.	013.00	7-03-66	080.00	AGING	NONE	0.0340	0.1430	096.80	2000.00	
BAA	0001037.	0373.	074.00	8-02-71	080.00	AGING	DFIRE	0.0480	0.1680	000.00	1920.00	
BAA	0000373.	0373.	078.00		080.00	AGING	NONE	0.0340	0.1710	096.20	1900.00	
BAA	0000451.	0373.	078.00		080.00	AGING	NONE	0.0240	0.1470	102.40	1777.00	
BAA	0001035.	0373.	066.00		080.00	AGING	NONE	0.0340	0.1600	099.70	1880.00	
BAA	0001036.	0373.	066.00		080.00	AGING	NONE	0.0260	0.1390	097.20	1910.00	
BAA	0000397.	0373.	000.00	6-22-65	080.00	LAT	NONE	0.0260	0.1700	101.70	1823.00	LAT
BAA	0000441.	0373.	000.00	6-22-65	080.00	LAT	NONE	0.0310	0.1610	100.90	1829.00	LAT
BAA	0000417.	0373.	000.00	6-25-65	080.00	LAT	NONE	0.0220	0.1450	100.70	1873.00	LAT
BAA	0000418.	0373.	000.00	7-06-65	080.00	LAT	NONE	0.0340	0.1650	101.63	1843.00	LAT
BAA	0000377.	0373.	000.00	7-07-65	080.00	LAT	NONE	0.0490	0.1630	097.80	1853.00	LAT
BAA	0000408.	0373.	000.00	7-08-65	080.00	LAT	NONE	0.0320	0.1550	098.10	1912.00	LAT
BAA	0000407.	0373.	000.00	7-07-65	080.00	LAT	NONE	0.0260	0.1460	101.40	1873.00	LAT
BAA	0000441.	0373.	096.00		080.00	AGING	NONE	0.0420	0.1730	103.10	1880.00	
BAA	0001016.	0373.	096.00		080.00	AGING	NONE	0.0500	0.1820	104.20	1760.00	
BAA	0001038.	0373.	223.00	4-06-84	080.00	AGING	NONE	0.0611	0.1800	103.62	1978.00	.32 SEC 1978 PSI
BAA	0001050.	0373.	223.00	4-17-84	080.00	AGING	NONE	0.0776	0.2070	101.15	1847.80	.34 SEC 1847 PSI
BAA	0001039.	0373.	236.00	5-23-85	080.00	AGING	NONE	0.0314	0.1365	097.96	2054.00	IN SPEC

Blend 368

GO TYPE	SERIAL NO	BLEND	GG AGE MO	TEST DATE	AGING TEMP F	GG TEST TYPE	VIBRATION	IGNITION DELAY SEC	IGNITION TIME SEC	BURN DURATION SEC	MEOP PSIA	COMMENTS
CAA	0001056.	0368.	018.00		080.00	AGING	NONE	0.0200	0.1450	077.90	0000.00	
CAA	0001090.	0368.	018.00		080.00	AGING	NONE	0.0160	0.2670	080.10	0000.00	
CAA	0001147.	0368.	116.00		080.00	AGING	NONE	0.0160	0.1660	078.60	0000.00	TESTED AT 80F
CAA	0001148.	0368.	158.00		080.00	AGING	NONE	0.0098	0.2300	000.00	0000.00	
CAA	0001107.	0368.	189.00	5-21-81	080.00	OPTEST	NONE	0.0077	0.0850	082.00	0759.20	OP-55
CAA	0001070.	0368.	182.00		080.00	AGING	NONE	0.0110	0.1580	079.99	0000.00	
CAA	0000385.	0368.	000.00	7-24-65	080.00	LAT	NONE	0.0150	0.1400	080.70	0767.00	LAT
CAA	0000451.	0368.	000.00	7-24-65	080.00	LAT	NONE	0.0090	0.1340	078.20	0924.00	LAT
CAA	0000446.	0368.	000.00	7-24-65	080.00	LAT	NONE	0.0480	0.1270	078.20	1041.00	LAT
CAA	0000441.	0368.	000.00	7-26-65	080.00	LAT	NONE	0.0130	0.1400	078.15	0823.00	LAT
CAA	0000452.	0368.	000.00	7-27-65	080.00	LAT	NONE	0.0140	0.1500	078.50	0848.00	LAT
CAA	0000448.	0368.	000.00	7-27-65	080.00	LAT	NONE	0.0110	0.1560	078.35	0843.00	LAT
CAA	0000443.	0368.	000.00	7-30-65	080.00	LAT	NONE	0.0110	0.1600	077.80	0742.00	LAT
CAA	0001074.	0368.	224.00	5-01-84	080.00	AGING	NONE	0.0347	0.1940	079.30	0704.00	.5 SEC TO MEOP
CAA	0001079.	0368.	236.50	5-24-85	080.00	AGING	NONE	0.0078	0.1934	077.75	0841.70	IN SPEC
CAA	0001102.	0368.	236.00	5-31-85	080.00	AGING	PFIRE	0.0069	0.0769	078.67	0856.00	IN SPEC
CAA	0001084.	0368.	236.00	6-06-85	080.00	AGING	NONE	0.0088	0.1500	077.34	0769.90	IN SPEC

Figure C-1. Minuteman Gas Generator Data
Blend 373 and Blend 368

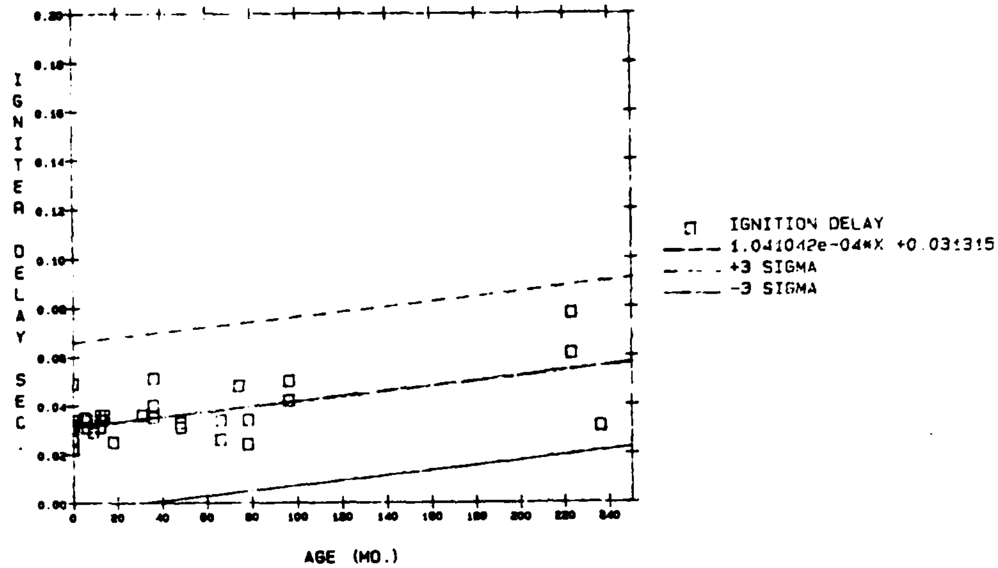
Blend 374

GG TYPE	SERIAL NO	BLEND	GG AGE MO	TEST DATE	AGING TEMP F	GG TEST TYPE	VIBRATION	IGNITION DELAY SEC	IGNITION TIME SEC	BURN DURATION SEC	MEOP PSIA	COMMENTS
BAA	0001033.	0374.	060.00		080.00	AGING	NONE	0.0280	0.1300	093.00	2033.00	
BAA	0001046.	0374.	010.00	3-26-66	080.00	AGING	NONE	0.0270	0.1080	094.50	2150.00	
BAA	0001045.	0374.	010.00	3-26-66	080.00	AGING	NONE	0.0280	0.1240	099.60	2110.00	
BAA	0001029.	0374.	030.00		080.00	AGING	NONE	0.0300	0.1170	093.00	2044.00	
BAA	0001030.	0374.	030.00		080.00	AGING	NONE	0.0380	0.1540	094.50	1943.00	
BAA	0001032.	0374.	060.00	8-26-70	080.00	AGING	DFIRE	0.0280	0.1300	093.00	0000.00	
BAA	0001034.	0374.	091.00		080.00	AGING	NONE	0.0330	0.1320	093.48	2120.00	
BAA	0001040.	0374.	091.00		080.00	AGING	NONE	0.0320	0.1240	093.91	2130.00	
BAA	0001052.	0374.	145.00	5-20-76	080.00	OPTEST	NONE	0.0500	0.1520	000.00	1974.00	OP-27
BAA	0001059.	0374.	138.00	5-12-77	080.00	OPTEST	NONE	0.0300	0.1600	096.00	2153.00	OP-34
BAA	0001067.	0374.	156.00	12-08-78	080.00	OPTEST	NONE	0.0370	0.1520	098.10	2198.00	OP-47
BAA	0001062.	0374.	186.00	5-21-81	080.00	OPTEST	NONE	0.0410	0.1310	094.00	1963.00	OP-49
BAA	0001060.	0374.	176.00	8-24-79	080.00	OPTEST	NONE	0.0440	0.1480	000.00	2068.00	OP-50
BAA	0001061.	0374.	182.00	1-22-81	080.00	OPTEST	NONE	0.0460	0.1800	094.60	2068.00	OP-51
BAA	0000389.	0374.	000.00	8-12-65	080.00	LAT	NONE	0.0240	0.1320	093.10	2029.00	LAT
BAA	0000410.	0374.	000.00	8-14-65	080.00	LAT	NONE	0.0340	0.1540	096.49	1892.00	
BAA	0000421.	0374.	000.00	8-13-65	080.00	LAT	NONE	0.0240	0.1340	103.00	1958.00	LAT-ANOMALY CAUSED LONG BURN
BAA	0000388.	0374.	000.00	8-13-65	080.00	LAT	NONE	0.0250	0.1350	095.80	2001.00	LAT
BAA	0000412.	0374.	000.00	8-19-65	080.00	LAT	NONE	0.0290	0.1300	095.75	2050.00	LAT
BAA	0000426.	0374.	000.00	8-17-65	080.00	LAT	NONE	0.0220	0.1200	091.72	2080.00	LAT
BAA	0000348.	0374.	000.00	8-19-65	080.00	LAT	NONE	0.0260	0.1500	094.60	1991.00	LAT
BAA	0001044.	0374.	223.00	4-10-84	080.00	AGING	NONE	0.1150	0.1860	000.00	2114.00	P-1 PLUGGED-.729 SEC 2114 PSI
BAA	0001072.	0374.	222.00	4-18-84	080.00	AGING	NONE	0.0683	0.1910	094.66	2092.00	.33 SEC 2092 PSI
BAA	0001075.	0374.	235.00	5-17-85	080.00	AGING	NONE	0.0500	0.1523	092.00	2243.00	IN SPEC

Blends 408 and 413

GG TYPE	SERIAL NO	BLEND	GG AGE MO	TEST DATE	AGING TEMP F	GG TEST TYPE	VIBRATION	IGNITION DELAY SEC	IGNITION TIME SEC	BURN DURATION SEC	MEOP PSIA	COMMENTS
CAA	0003042.	0408.	219.00	5-17-85	080.00	AGING	NONE	0.0102	0.1161	078.01	1074.00	TAA3042--LOT REQUAL
BAA	0003068.	0413.	217.00	5-13-85	080.00	AGING	NONE	0.0250	0.1270	090.94	2198.00	RAA3068--LOT REQUAL

Figure C-2. Minuteman Gas Generator Data Blends 374, 408, and 413



Parameter Table

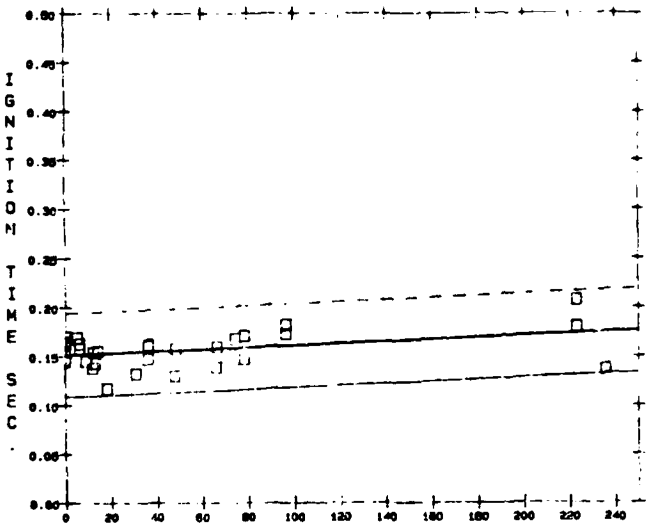
0	1 PARAMETER	2 VALUE	3 STANDARD DEVIATION	4 T-VALUE	5 SIG. LEV.
1	INTERCEPT	0.031315	0.002090	14.980592	0.0001
2	SLOPE	0.000104	0.000026	4.039754	0.0010

Analysis of Variance Table

0	1 SOURCE	2 SUM OF SQUARES	3 D.F.	4 MEAN SQUARE	5 F VALUE	6 SIG. LEV.	7 MULT R-SQ
1	REGRESSION	0.001451	1	0.001451	16.31961	0.001	0.35[illegible]
2	RESIDUAL	0.002668	30	0.000089			

0	8 STD DEV OF REGR
1	0.00943
2	

Figure C-3. Ignition Delay vs Age - Blend 373, 1985 RC Gas Generator Analysis



Parameter Table

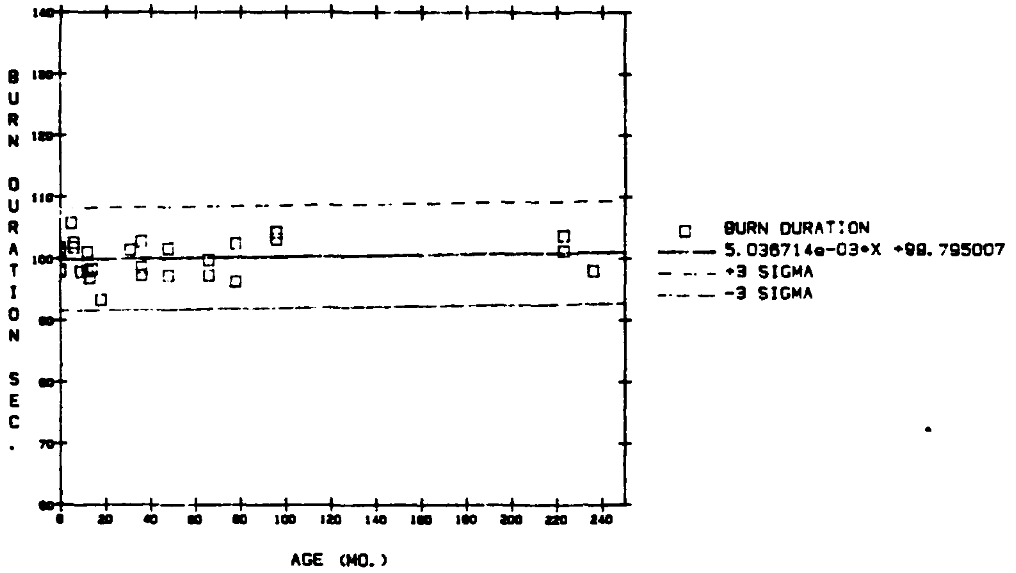
0	1 PARAMETER	2 VALUE	3 STANDARD DEVIATION	4 T-VALUE	5 SIG. LEV.
1	INTERCEPT	0.151331	0.003677	41.156322	0.000100
2	SLOPE	0.000100	0.000045	2.210192	0.034862

Analysis of Variance Table

0	1 SOURCE	2 SUM OF SQUARES	3 D.F.	4 MEAN SQUARE	5 F VALUE	6 SIG. LEV.	7 MULT R-SQ
1	REGRESSION	0.001344	1	0.001344	4.88495	0.035	0.140
2	RESIDUAL	0.008255	30	0.000275			

0	8 STD DEV OF REGR
1	0.016588
2	

Figure C-4. Ignition Time vs Age - Blend 373, 1985 RC Gas Generator Analysis



Parameter Table

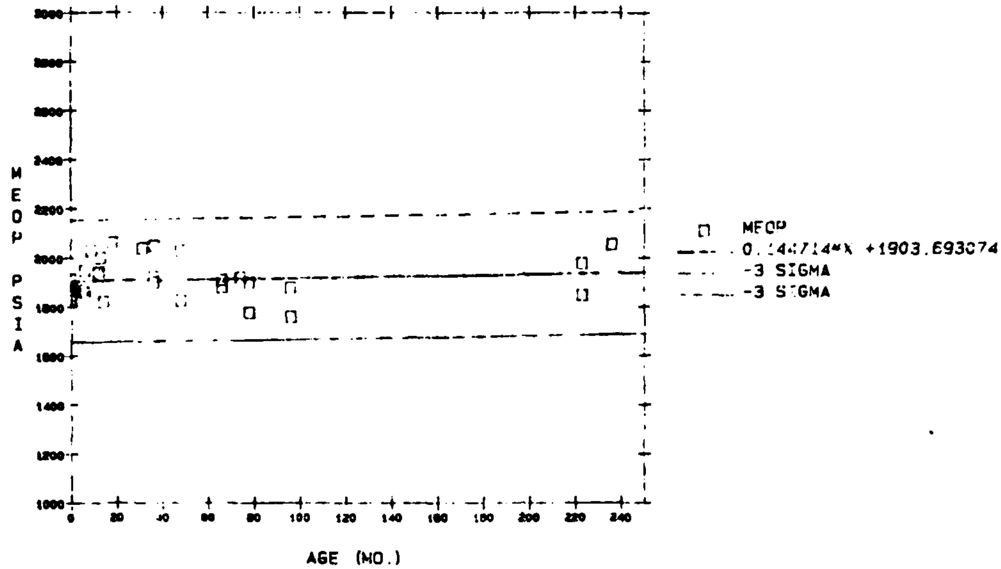
0	1 PARAMETER	2 VALUE	3 STANDARD DEVIATION	4 T-VALUE	5 SIG. LEV.
1	INTERCEPT	99.795007	0.625346	159.583617	0.000100
2	SLOPE	0.005037	0.007689	0.655097	0.517568

Analysis of Variance Table

0	1 SOURCE	2 SUM OF SQUARES	3 D.F.	4 MEAN SQUARE	5 F VALUE	6 SIG. LEV.
1	REGRESSION	3.380846	1	3.380846	0.429152	0.52
2	RESIDUAL	228.461148	29	7.877971		

0	7 MULT R-SQ	8 STD DEV OF REGR
1	0.014583	2.806772
2		

Figure C-5. Burn Duration vs Age - Blend 373, 1985 RC Gas Generator Analysis



Parameter Table

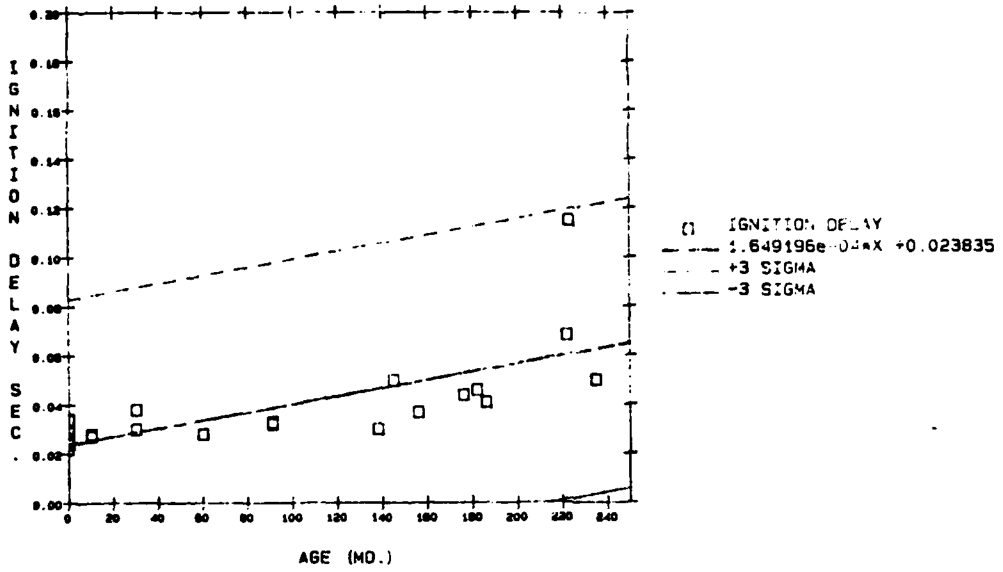
0	1 PARAMETER	2 VALUE	3 STANDARD DEVIATION	4 T-VALUE	5 SIG. LEV.
1	INTERCEPT	1903.693074	18.652758	102.059600	0.000100
2	SLOPE	0.144714	0.229952	0.629323	0.533901

Analysis of Variance Table

0	1 SOURCE	2 SUM OF SQUARES	3 D.F.	4 MEAN SQUARE	5 F VALUE	6 SIG. LEV.
1	REGRESSION	2804.515156	1	2804.515156	0.396047	0.5[illegible]
2	RESIDUAL	212438.104844	30	7081.270161		

0	7 MULT R-SQ	8 STD DEV OF REGR
1	0.01303	84.150[illegible]83
2		

Figure C-6. MEOP vs Age - Blend 373, RC Gas Generator Analysis



Parameter Table

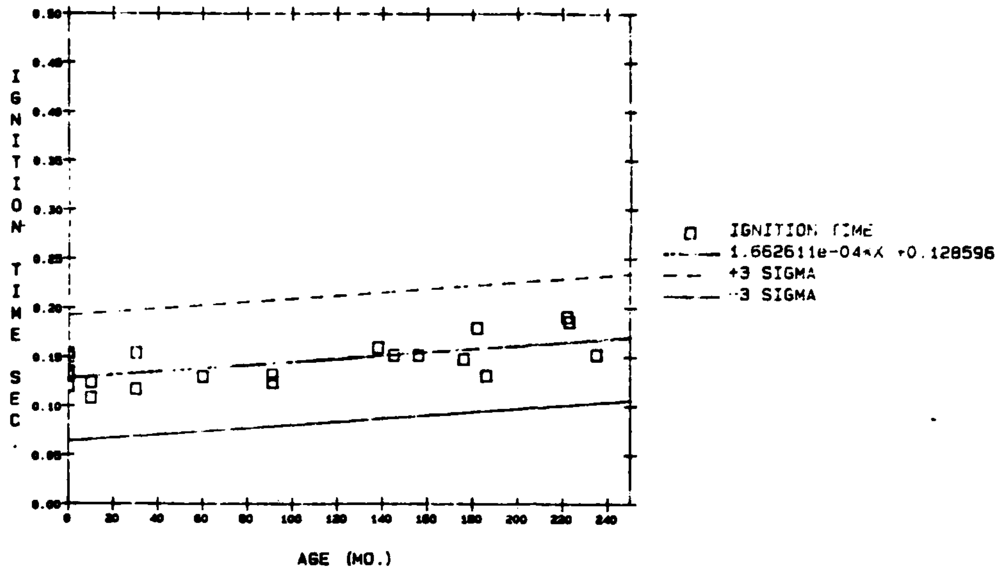
0	1 PARAMETER	2 VALUE	3 STANDARD DEVIATION	4 T-VALUE	5 SIG. LEV.
1	INTERCEPT	0.023835	0.004078	5.845383	0.0001
2	SLOPE	0.000165	0.000034	4.835883	0.0010

Analysis of Variance Table

0	1 SOURCE	2 SUM OF SQUARES	3 D.F.	4 MEAN SQUARE	5 F VALUE	6 SIG. LEV.
1	REGRESSION	0.004592	1	0.004592	23.385757	0.001
2	RESIDUAL	0.004320	22	0.000196		

0	7 MULT R-SQ	8 STD DEV OF REGR
1	0.515266	0.014014
2		

Figure C-7. Ignition Delay vs Age - Blend 374, 1985 RC Gas Generator Analysis



Parameter Table

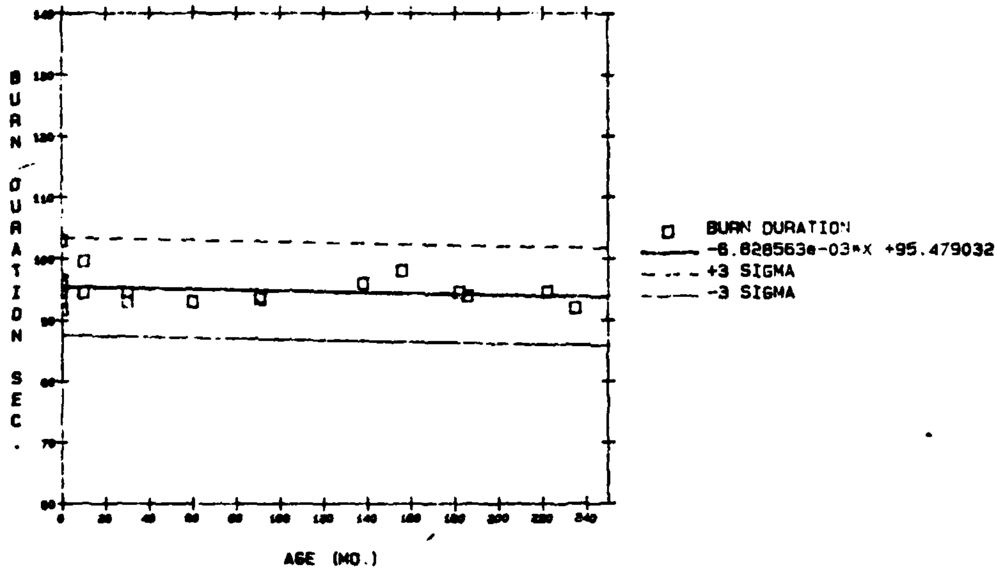
0	1 PARAMETER	2 VALUE	3 STANDARD DEVIATION	4 T-VALUE	5 SIG. LEV.
1	INTERCEPT	0.128596	0.004764	26.994786	0.0001
2	SLOPE	0.000166	0.000040	4.173013	0.0010

Analysis of Variance Table

0	1 SOURCE	2 SUM OF SQUARES	3 D.F.	4 MEAN SQUARE	5 F VALUE	6 SIG. LEV.
1	REGRESSION	0.004667	1	0.004667	17.414034	0.001
2	RESIDUAL	0.005697	22	0.000268		

0	7 MULT R-SQ	8 STD DEV OF REGR
1	0.441823	0.016372
2		

Figure C-8. Ignition Time vs Age - Blend 374, 1985 RC Gas Generator Analysis



Parameter Table

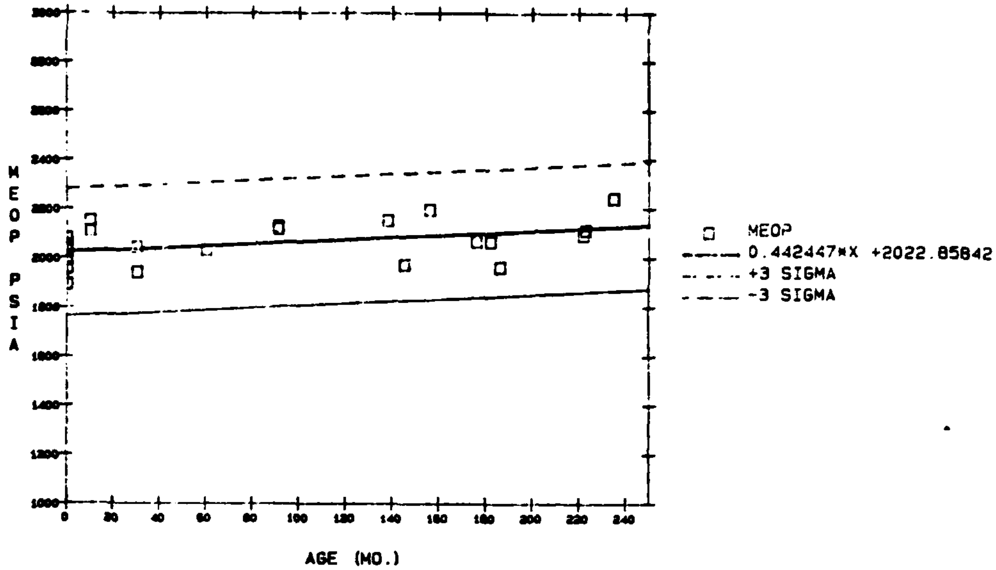
0	1 PARAMETER	2 VALUE	3 STANDARD DEVIATION	4 T-VALUE	5 SIG. LEV.
1	INTERCEPT	95.479032	0.776780	122.916441	0.000100
2	SLOPE	-0.006829	0.007245	-0.942463	0.357786

Analysis of Variance Table

0	1 SOURCE	2 SUM OF SQUARES	3 D.F.	4 MEAN SQUARE	5 F VALUE	6 SIG. LEV.
1	REGRESSION	6.252298	1	6.252298	0.888236	0.36
2	RESIDUAL	133.741083	19	7.039004		

0	7 MULT R-SQ	8 STD DEV OF REGR
1	0.044661	2.653112
2		

Figure C-9. Burn Duration vs Age - Blend 374, 1985 RC Gas Generator Analysis



Parameter Table

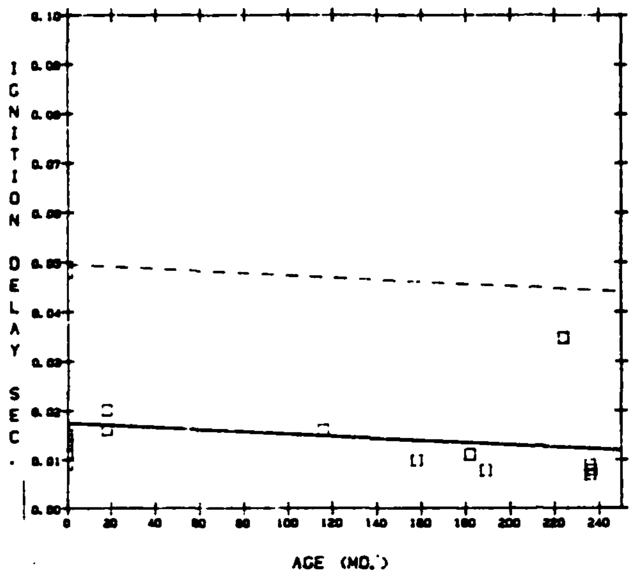
0	1 PARAMETER	2 VALUE	3 STANDARD DEVIATION	4 T-VALUE	5 SIG. LEV.
1	INTERCEPT	2022.858420	23.417247	86.383272	0.000100
2	SLOPE	0.442447	0.192743	2.295523	0.032102

Analysis of Variance Table

0	1 SOURCE	2 SUM OF SQUARES	3 D.F.	4 MEAN SQUARE	5 F VALUE	6 SIG. LEV
1	REGRESSION	32924.080904	1	32924.080904	5.269424	0.03
2	RESIDUAL	131210.875617	21	6248.136934		

0	7 MULT R-SQ	8 STD DEV OF REGR
1	0.200592	79.045158
2		

Figure C-10. MEOP vs Age - Blend 374, 1985 RC Gas Generator Analysis



Parameter Table

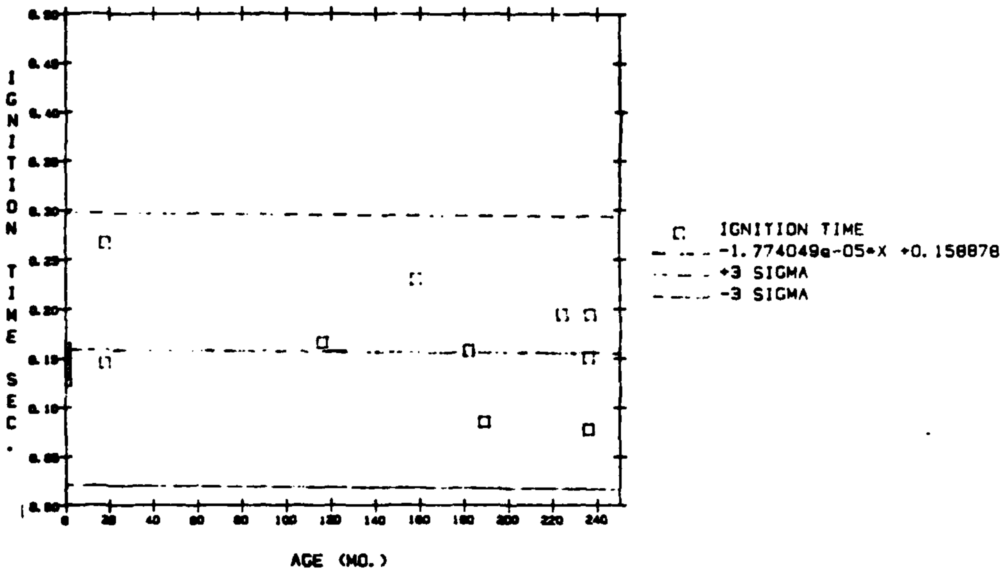
0	1 PARAMETER	2 VALUE	3 STANDARD DEVIATION	4 T-VALUE	5 SIG. LEV.
1	INTERCEPT	0.017379	0.003594	4.835896	0.00100
2	SLOPE	-0.000022	0.000026	-0.852822	0.40717

Analysis of Variance Table

0	1 SOURCE	2 SUM OF SQUARES	3 D.F.	4 MEAN SQUARE	5 F VALUE	6 SIG. LEV.	7 MULT R-SQ
1	REGRESSION	0.000085	1	0.000085	0.727306	0.41	0.04624
2	RESIDUAL	0.001743	15	0.000116			

0	8 STD DEV OF REGR
1	0.010781
2	

Figure C-11. Ignition Delay vs Age - Blend 368, 1985 TVC Gas Generator Analysis



Parameter Table

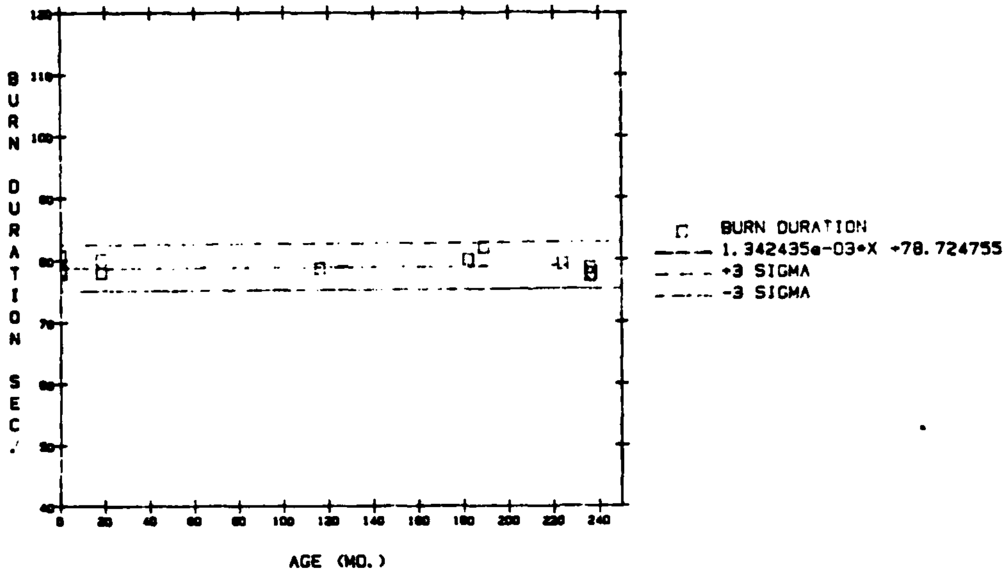
0	1 PARAMETER	2 VALUE	3 STANDARD DEVIATION	4 T-VALUE	5 SIG. LEV.
1	INTERCEPT	0.158878	0.015872	10.009839	0.000100
2	SLOPE	-0.000018	0.000115	-0.154640	0.879167

Analysis of Variance Table

0	1 SOURCE	2 SUM OF SQUARES	3 D.F.	4 MEAN SQUARE	5 F VALUE	6 SIG. LEV.	7 MULT R-SQ
1	REGRESSION	0.000054	1	0.000054	0.023914	0.88	0.0015[illegible]
2	RESIDUAL	0.034009	15	0.002267			

0	8 STD DEV OF REGR
1	0.047616
2	

Figure C-12. Ignition Time vs Age - Blend 368,
1985 TVC Gas Generator Analysis



Parameter Table

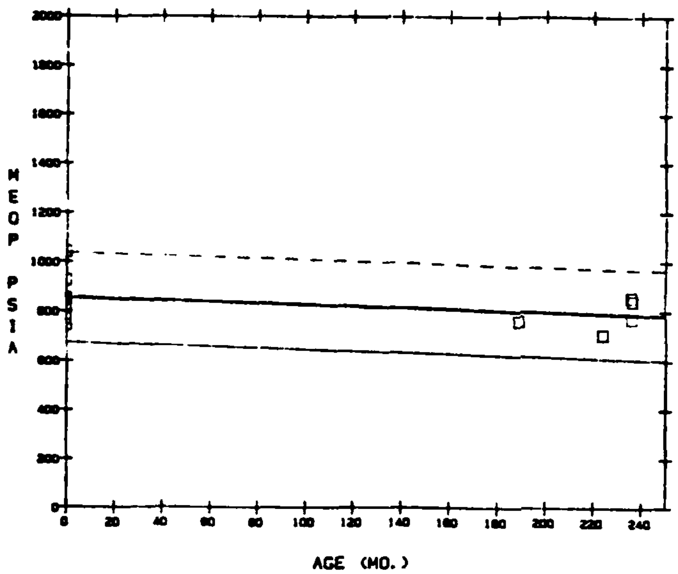
0	1 PARAMETER	2 VALUE	3 STANDARD DEVIATION	4 T-VALUE	5 SIG. LEV.
1	INTERCEPT	78.724755	0.432211	182.144284	0.000100
2	SLOPE	0.001342	0.003154	0.425621	0.676854

Analysis of Variance Table

0	1 SOURCE	2 SUM OF SQUARES	3 D.F.	4 MEAN SQUARE	5 F VALUE	6 SIG. LEV.
1	REGRESSION	0.302838	1	0.302838	0.181153	0.68
2	RESIDUAL	23.404106	14	1.671722		

0	7 MULT R-SQ	8 STD DEV OF REGR
1	0.012774	1.292951
2		

Figure C-13. Burn Duration vs Age - Blend 368, 1985 TVC Gas Generator Analysis



Parameter Table

0	1 PARAMETER	2 VALUE	3 STANDARD DEVIATION	4 T-VALUE	5 SIG. LEV.
1	INTERCEPT	853.66771	33.367615	25.583720	0.000100
2	SLOPE	-0.28998	0.229702	-1.262415	0.235445

Analysis of Variance Table

0	1 SOURCE	2 SUM OF SQUARES	3 D.F.	4 MEAN SQUARE	5 F VALUE	6 SIG. LEV
1	REGRESSION	12479.364703	1	12479.364703	1.593692	0.2
2	RESIDUAL	78304.721963	10	7830.472196		

0	7 MULT R-SQ	8 STD DEV OF REGR
1	0.137462	88.489955
2		

Figure C-14. MEOP vs Age - Blend 368, 1985 TVC Gas Generator Analysis

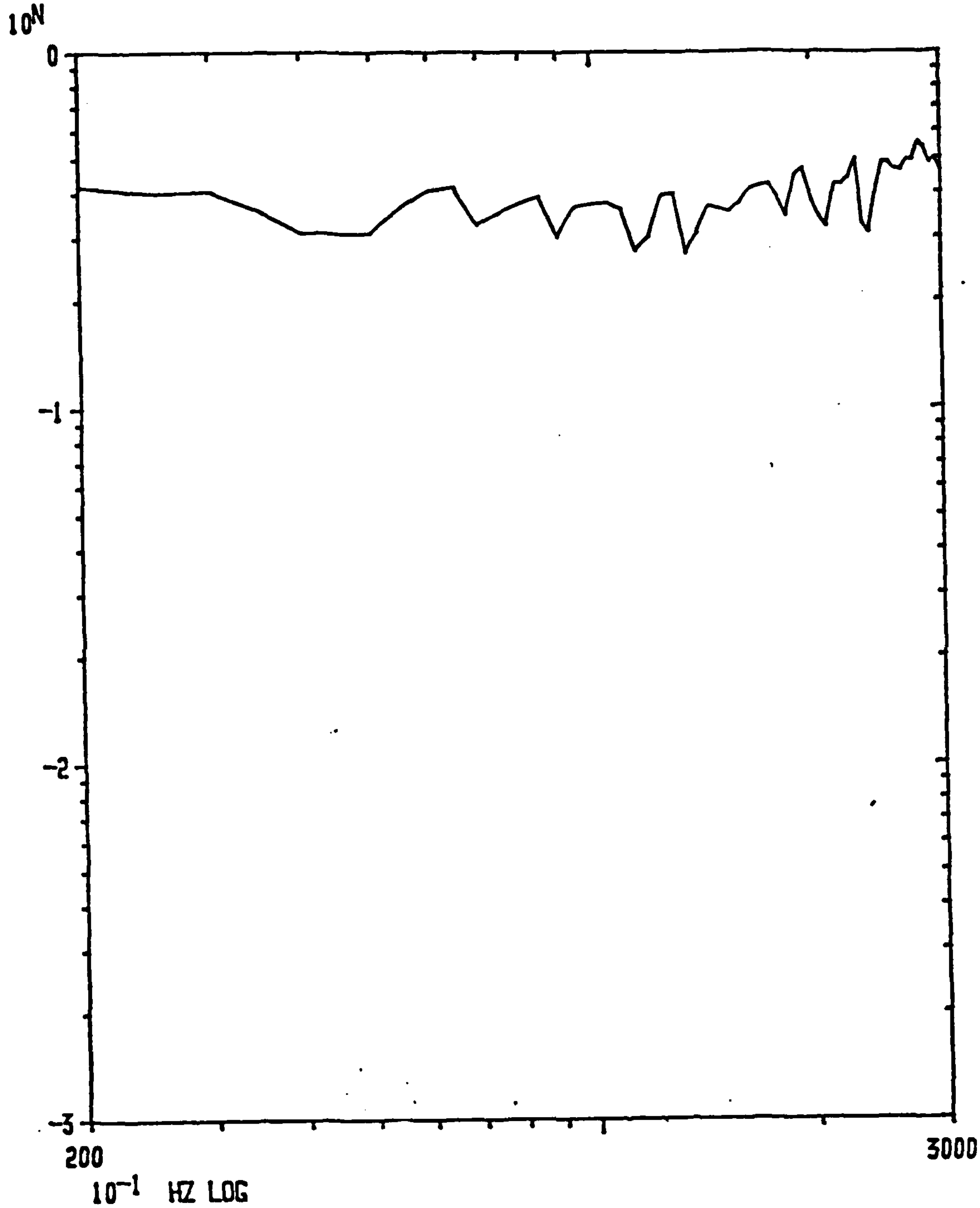


Figure C-15. A-3 Response 15-45 Sec Power Spectral Density
RMS Level = 10.52 GSQ D/HZ - ΔF = 5HZ, 72 Averages

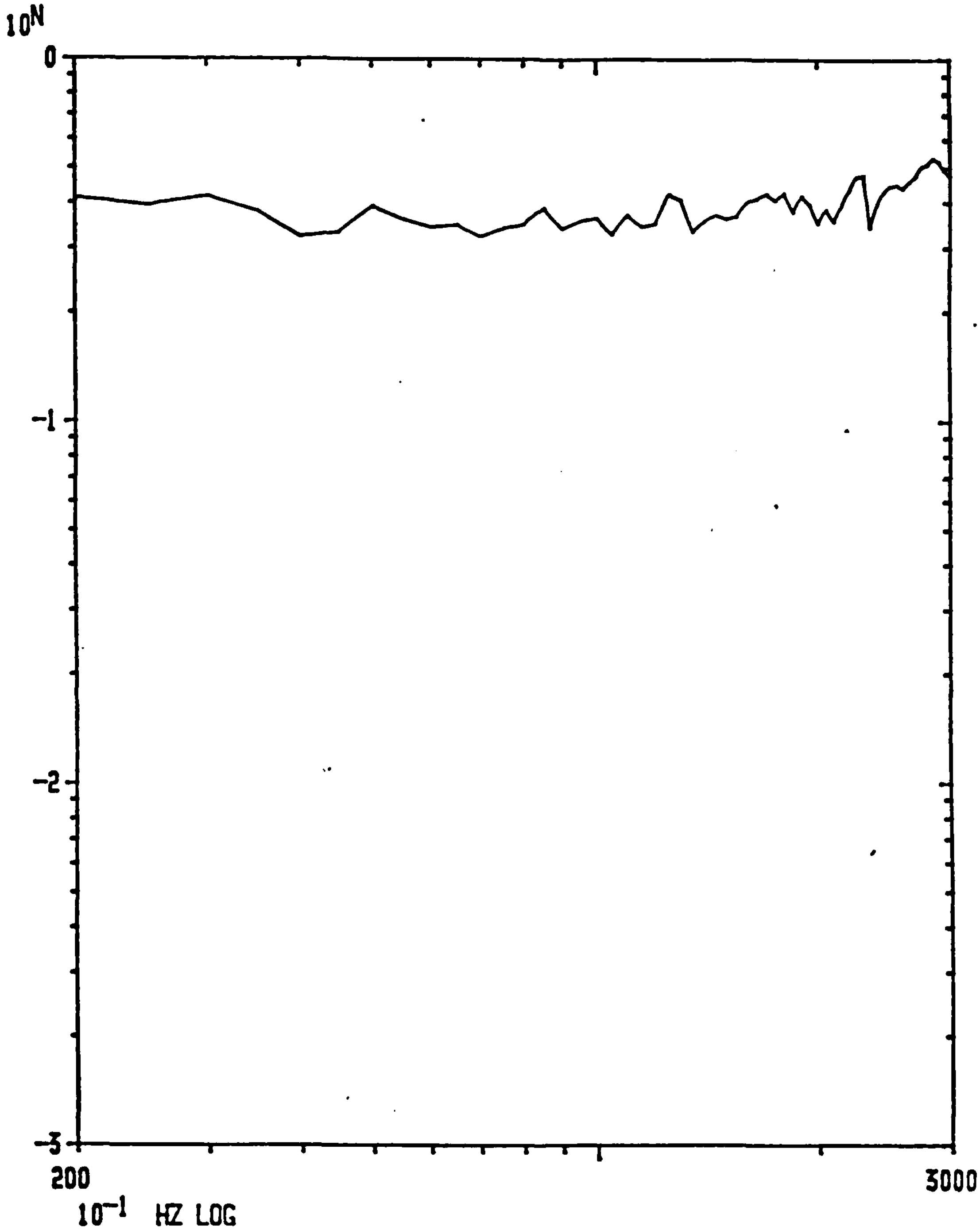


Figure C-16. A-3 Response 5-115 Sec Power Spectral Density
RMS Level = 10.56 G SQ D/HZ - ΔF = 5HZ 210 Averages

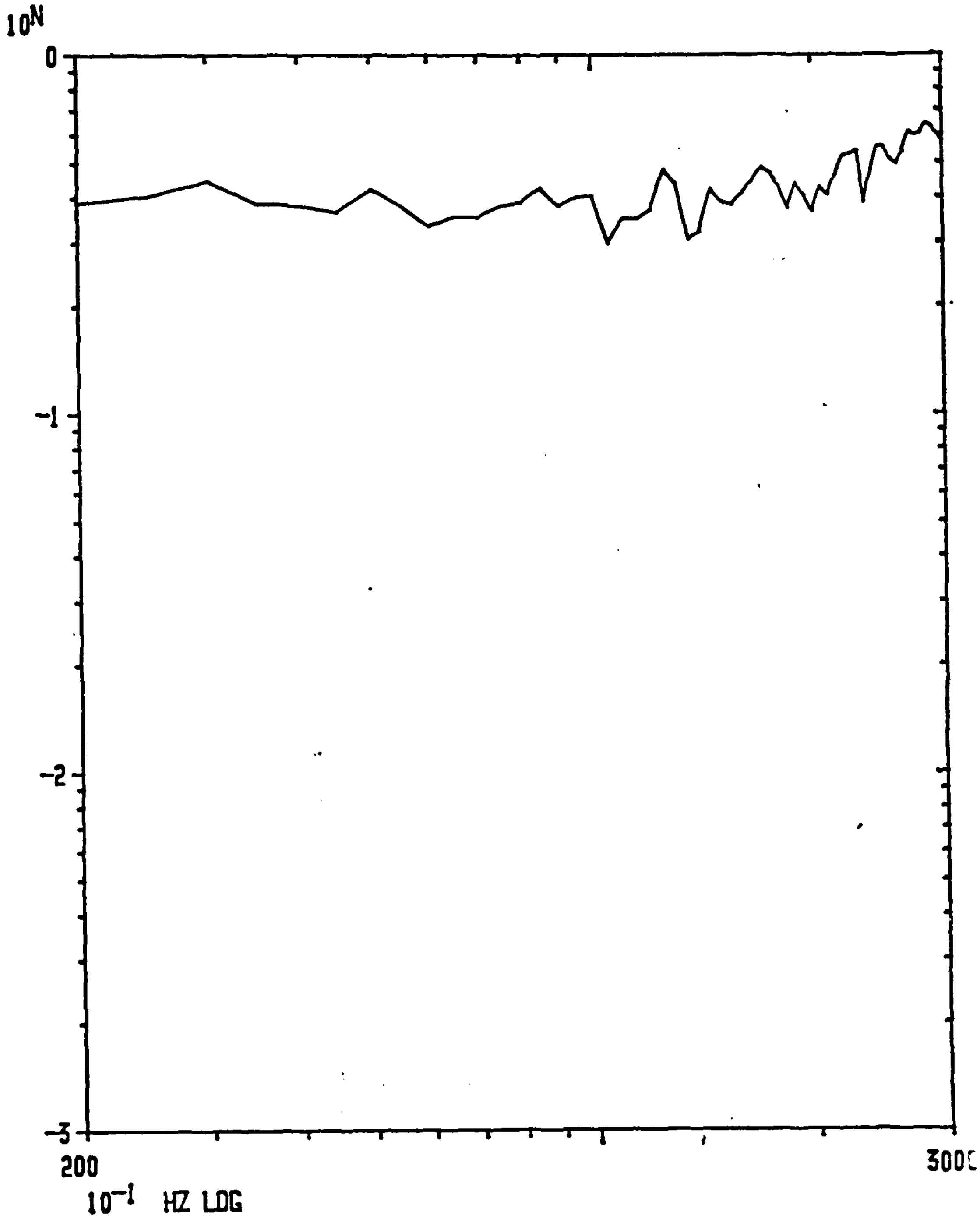


Figure C-17. A-2 Response 15-45 Sec Power Spectral Density
RMS Level = 11.10 G SQ D/HZ - ΔF = 5HZ 72 Averages

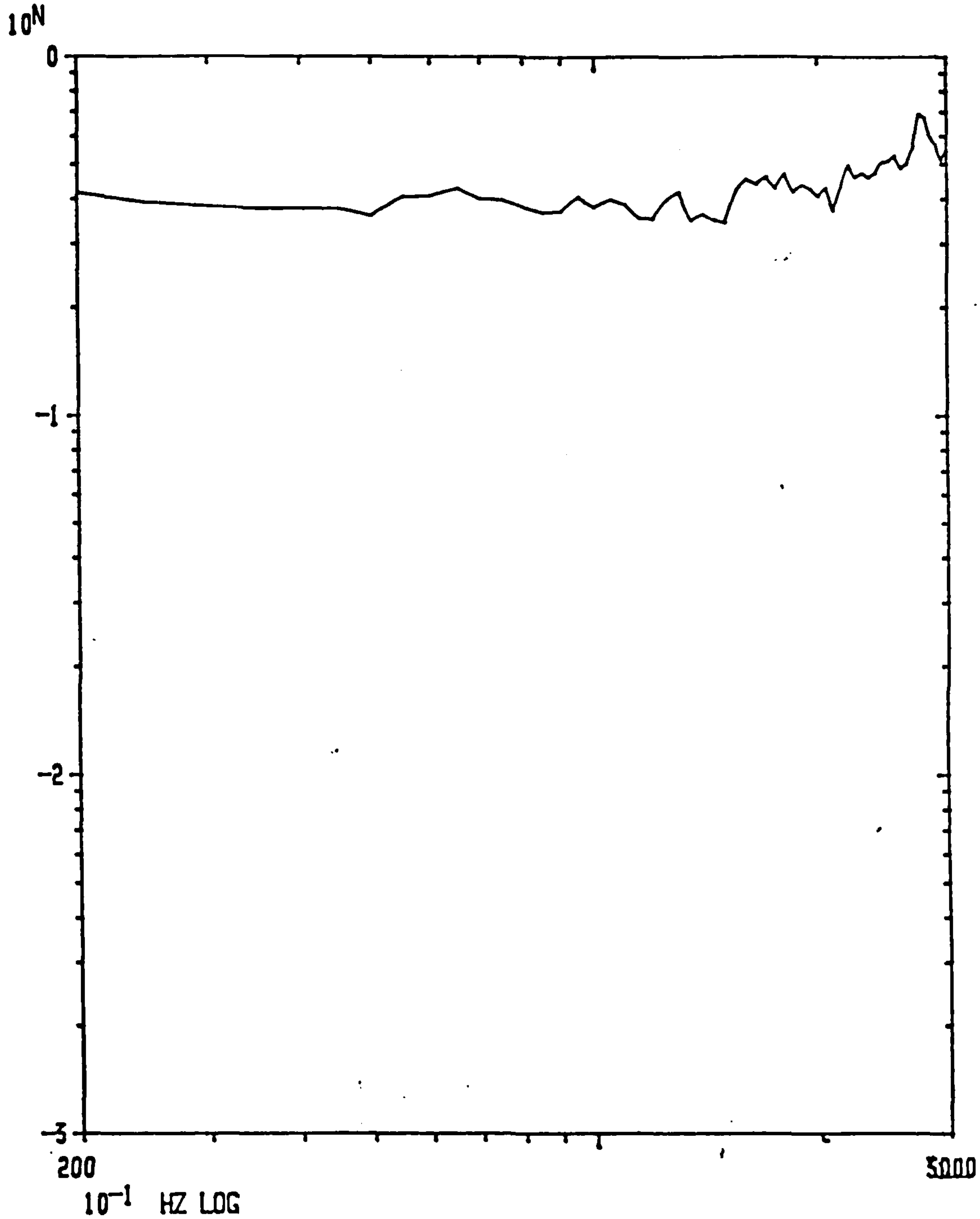


Figure C-18. A-2 Response 5-115 Sec Power Spectral Density
RMS Level = 11.08 G SQ D/HZ - .F + 5HZ 210 Averages

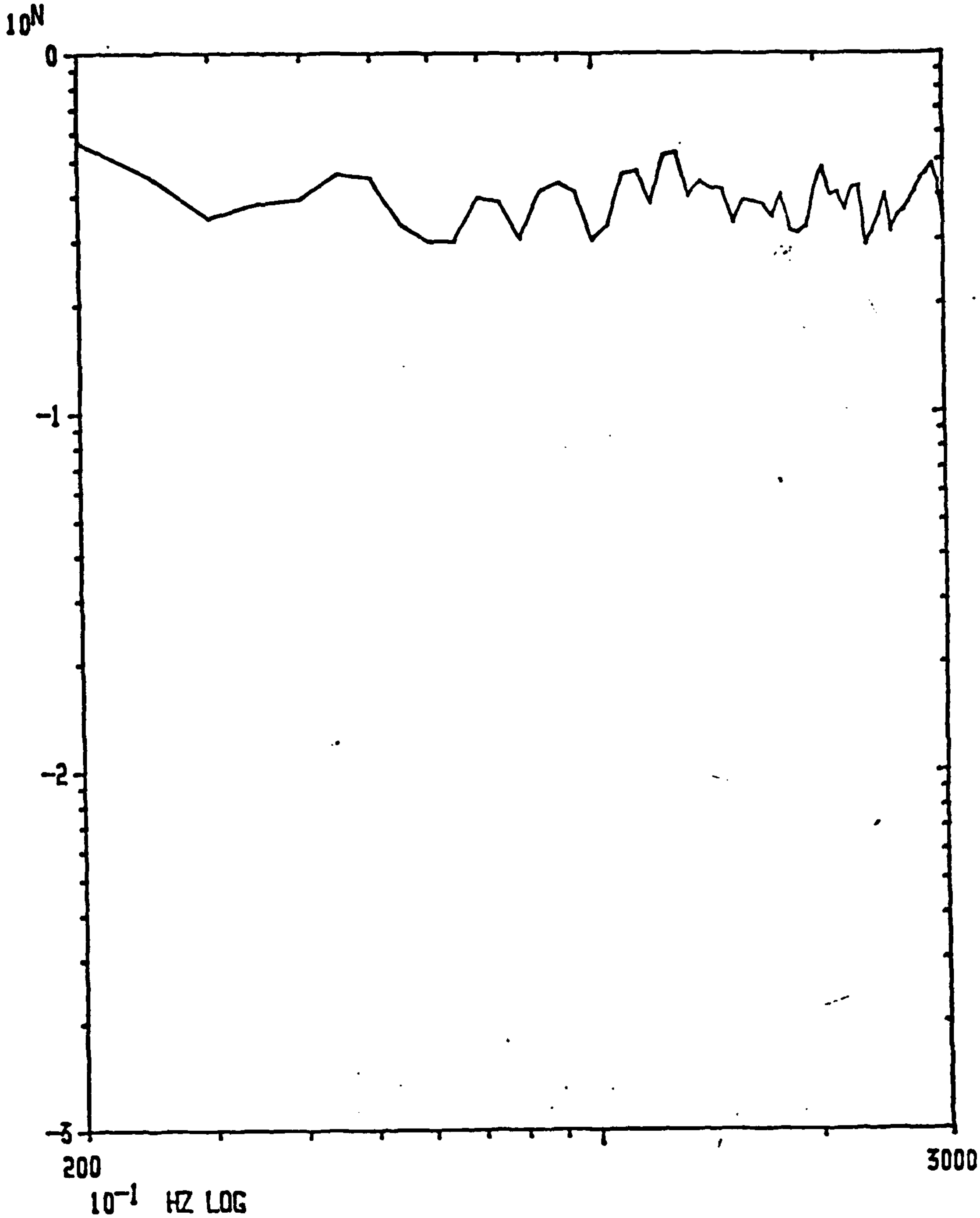


Figure C-19. A-1 Input Control 90-120 Sec Power Spectral Density
RMS Level = 10.48 G SQ D/HZ - ΔF = 5HZ, 72 Averages

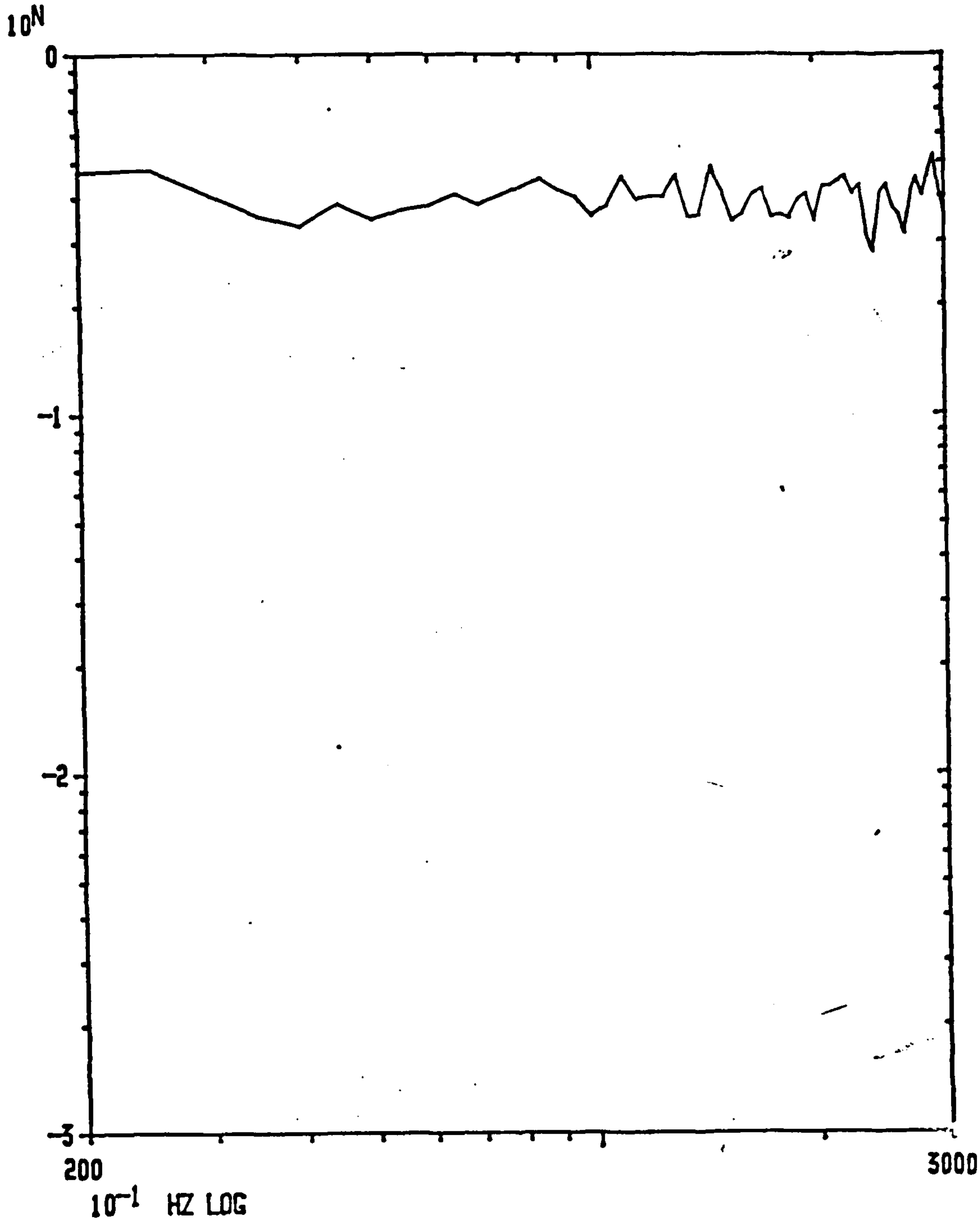


Figure C-20. A-1 Input Control 15-45 Sec Power Spectral Density
RMS Level = 10.55 G SQ D/HZ - ΔF = 5HZ 72 Averages

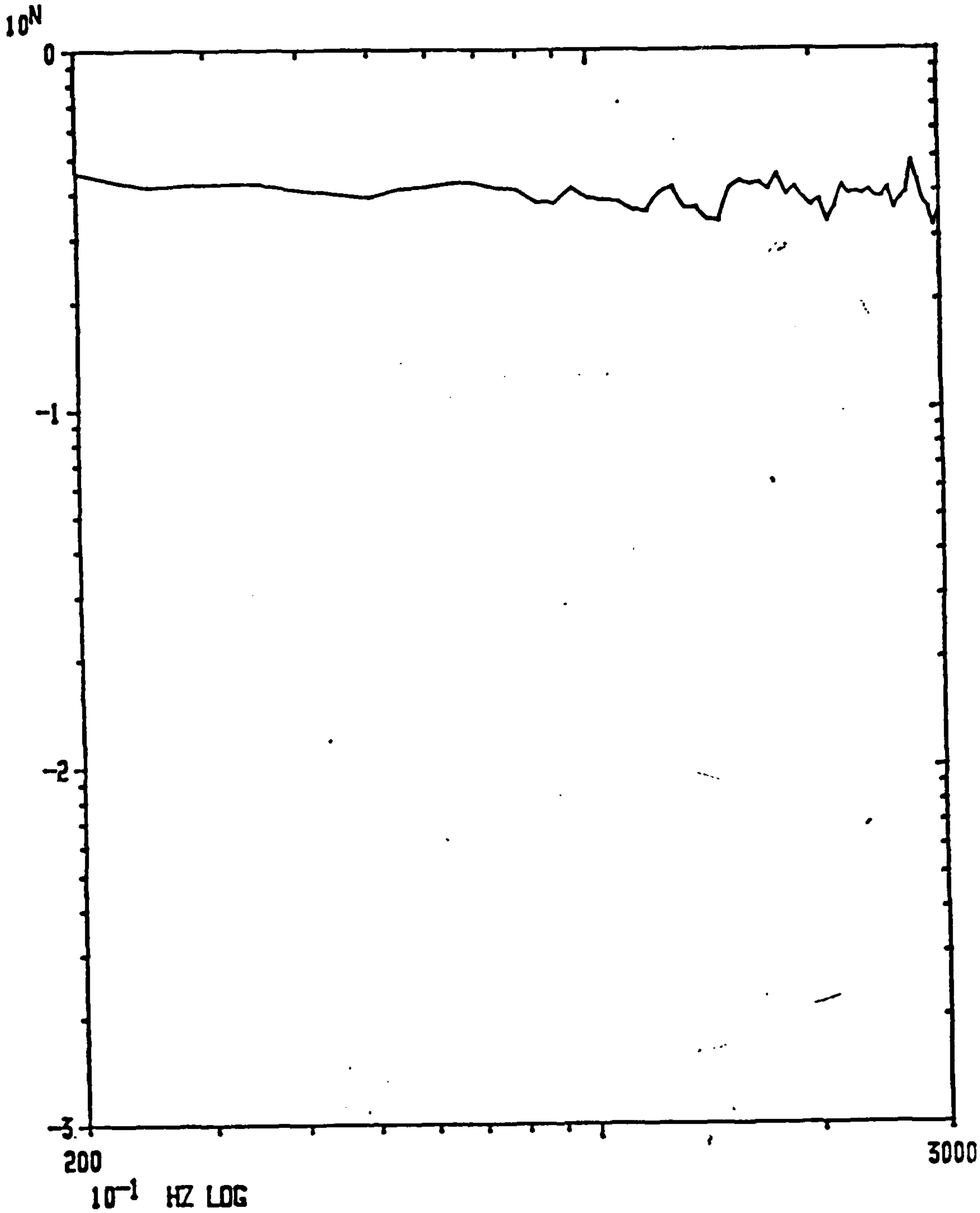
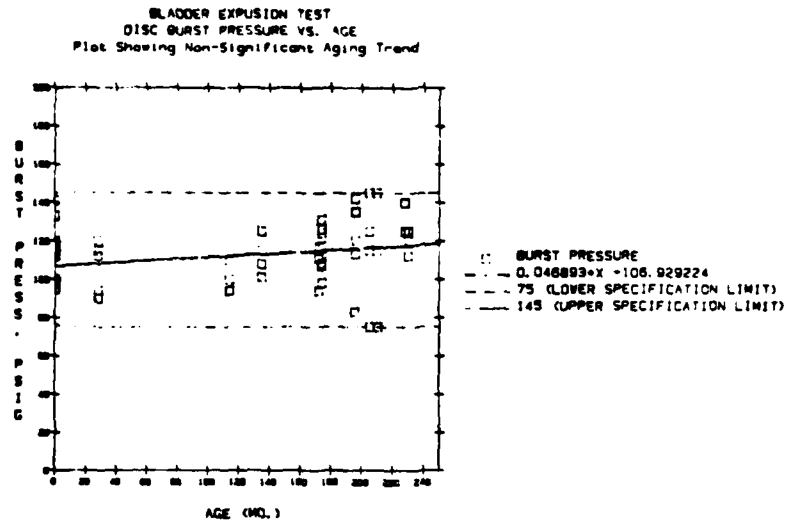


Figure C-21. A-1 Input Control Power Spectral Density
RMS Level = 10.49 G SQ D/HZ Composite for 5 to 115
Sec, ΔF = 5HZ, 210 Averages



ANALYSIS OF VARIANCE TABLE

0	1 DF	2 SS	3 MS=SS/DF	4 F VALUE	5 SIG LEVEL
1 FACTOR	10	4803.380096	480.338010	1.76	0.087
2 ERROR	60	16334.197368	272.236623		
3 TOTAL	70	21137.577465			

At a SIGNIFICANCE LEVEL of .05.
there is INSUFFICIENT EVIDENCE to REJECT the NULL HYPOTHESIS that the SAMPLES come from POPULATIONS with EQUAL MEANS.

LEVEL	N	MEAN	STDEV	INDIVIDUAL 95 PCT CI'S FOR MEAN BASED ON POOLED STDEV
0	19	111.053	16.033	(---*--)
98	8	101.625	12.225	(-----*-----)
114	4	99.500	7.550	(--------*-------)
135	4	112.250	10.243	(-------*-------)
172	4	108.250	9.912	(-------*-------)
174	8	115.375	11.160	(-----*-----)
196	8	122.000	19.250	(-----*-----)
~~205~~	4	115.000	29.439	(--------*-------)
210	4	102.500	34.034	(-------*--------)
228	4	132.500	8.660	(-------*--------)
230	4	120.500	6.137	(-------*-------)
				100 120 140

POOLED STDEV = 16.500

Figure C-22. Statistical Analysis for 1985 Disc Pressure Analysis

SN			[illegible]	BLADDER VENDOR
[illegible]	[illegible]	[illegible]	[illegible]	ARROWHEAD
[illegible]	[illegible]	[illegible]	[illegible]	ARROWHEAD
[illegible]	[illegible]	[illegible]	[illegible]	ARROWHEAD
ABB1008	0174	4	098	ARROWHEAD
ABB0589	0174	1	107	ARROWHEAD
ABB0589	0174	2	112	ARROWHEAD
[illegible]	[illegible]	[illegible]	[illegible]	ARROWHEAD
[illegible]	[illegible]	[illegible]	131	ARROWHEAD
ABB0623	[illegible]	[illegible]	094	ARROWHEAD
ABB0623	0172	2	111	ARROWHEAD
ABB0623	0172	3	111	ARROWHEAD
ABB0623	0172	4	117	ARROWHEAD
[illegible]	[illegible]	[illegible]	[illegible]	US RUBBER
[illegible]	[illegible]	[illegible]	101	US RUBBER
[illegible]	[illegible]	[illegible]	[illegible]	US RUBBER
ABB0069	0135	4	125	US RUBBER
ABB1042	0196	1	083	ARROWHEAD
ABB1042	0196	2	135	ARROWHEAD
[illegible]	[illegible]	[illegible]	[illegible]	ARROWHEAD
[illegible]	[illegible]	[illegible]	113	ARROWHEAD
[illegible]	[illegible]	[illegible]	142	ARROWHEAD
ABB1056	0196	2	135	ARROWHEAD
ABB1056	0196	3	120	ARROWHEAD
ABB1056	0196	4	113	ARROWHEAD
[illegible]	[illegible]	[illegible]	[illegible]	ARROWHEAD
[illegible]	[illegible]	[illegible]	075	ARROWHEAD
[illegible]	[illegible]	[illegible]	075	ARROWHEAD
CAC0041	0210	4	145	ARROWHEAD
A3B0555	0205	1	115	ARROWHEAD
ABB0555	0205	2	125	ARROWHEAD
[illegible]	[illegible]	[illegible]	145	ARROWHEAD
[illegible]	[illegible]	[illegible]	075	ARROWHEAD
T210	[illegible]	[illegible]	120	ARROWHEAD
T210	0028	2	115	ARROWHEAD
T210	0028	3	112	ARROWHEAD
T210	0023	4	100	ARROWHEAD
T159	[illegible]	[illegible]	090	ARROWHEAD
T159	[illegible]	[illegible]	092	ARROWHEAD
T159	[illegible]	[illegible]	090	ARROWHEAD
T159	0028	4	094	ARROWHEAD
20013	0114	1	100	-
20013	0114	2	110	-
20013	[illegible]	[illegible]	[illegible]	-
20013	[illegible]	[illegible]	[illegible]	-
[illegible]	[illegible]	[illegible]	125	ARROWHEAD
ABB0077	0228	2	140	ARROWHEAD
ABB0077	0228	3	140	ARROWHEAD
ABB0077	0228	4	125	ARROWHEAD
[illegible]	[illegible]	[illegible]	125	US RUBBER
[illegible]	[illegible]	[illegible]	120	US RUBBER
ABB0535	[illegible]	[illegible]	112	US RUBBER
ABB0535	0230	4	125	US RUBBER
-	0000	0	099	-
-	0000	0	099	-
-	0000	0	113	-
-	0000	0	115	-
-	0000	0	113	-
-	0000	0	117	-
-	0000	0	119	-
-	0000	0	112	-
-	0000	0	133	-
-	0000	0	133	-
-	0000	0	117	-
-	0000	0	096	-
-	0000	0	124	-
-	0000	0	112	-
-	0000	0	141	-
200039	0000	0	074	-
60095	0000	0	095	-
160044	0000	0	098	-
170000	0000	0	100	-

Figure C-23. Data Used for 1985 Disc Pressure Analysis

Appendix D

Manufacturing Variables Study Report

I. INTRODUCTION*

The nipple-propellant gap measurements taken on the Minuteman Wing VI, Stage II motors were used in conjunction with the data given in Reference 11 assessments:

1. To roughly characterize the nipple-propellant gap behavior from the available motor measurements (forward and aft boots).

2. To derive equations for the prediction of nipple-propellant gap from composition variables and excised motor test data.

3. To predict the rate of motor age-out as a function of motor age.

The following report addresses these objectives.

*Note: This report uses a forward boot gap of 0.03 in. as a failure criteria; this value is actually the "alert" value established by OO-ALC for further motor inspection.

II. CHARACTERIZATION OF GAP BEHAVIORS IN AGED MOTORS

Measurements by Aerojet and OO-ALC of the nipple propellant gap in aged motors have been compiled for both the forward and aft boots. Using this data compilation it was possible to approximate the rates of motor age-out as a function of age.

A. AGE-OUT AT THE FORWARD BOOT

Earlier assessments indicated distinct differences in the behaviors of the liner batches made using the CTPB polymer from the two vendors, GT&R and Phillips. That distinction was assumed to apply to these data, so the data were separately treated.

Figure D-1 presents the raw data for those motors using the GT&R polymer. Two values are plotted. The first curve gives the cumulative number of motors tested for nipple-propellant gap opening (Σ N) versus the age of the motors in months. The second curve is a plot of the cumulative number of motors that exceeded the age-out criterion (Σ F), also plotted versus motor age.

Figure D-2 give raw data curves for Phillips polymer.

The approximate age-out rate at each age for this motor sampling is given by the relation

$$\text{Age-Out Rate} = \Sigma F / \Sigma N \qquad (1)$$

Figures D-3 and D-4 show these rates versus motor age for the GT&R and Phillips polymers, respectively.

Figure D-5 was prepared for a simple comparison of the two distribution curves. Except for a few early age-out motors, those using the Phillips

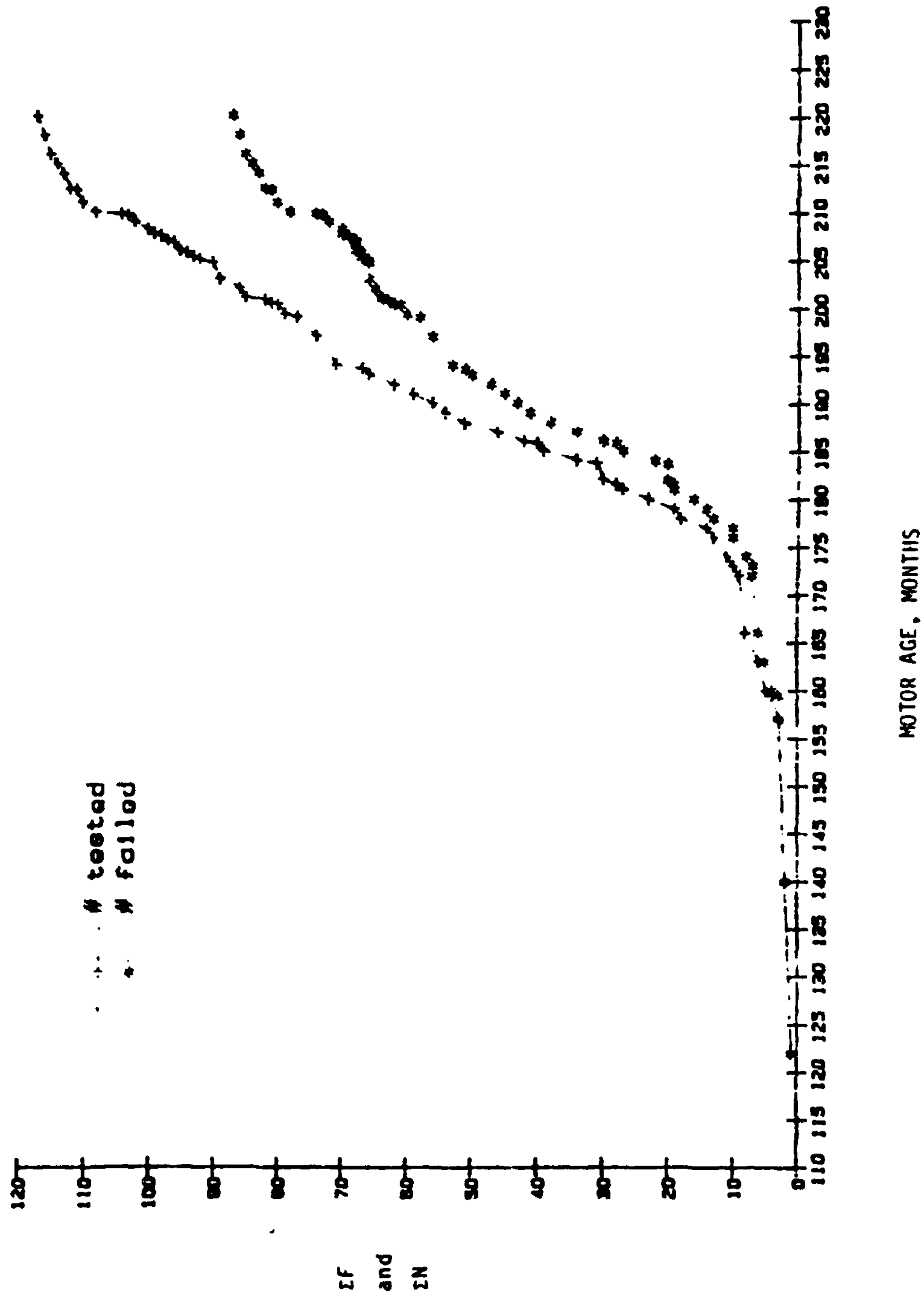


Figure D-1. Cumulative Distribution for GTR

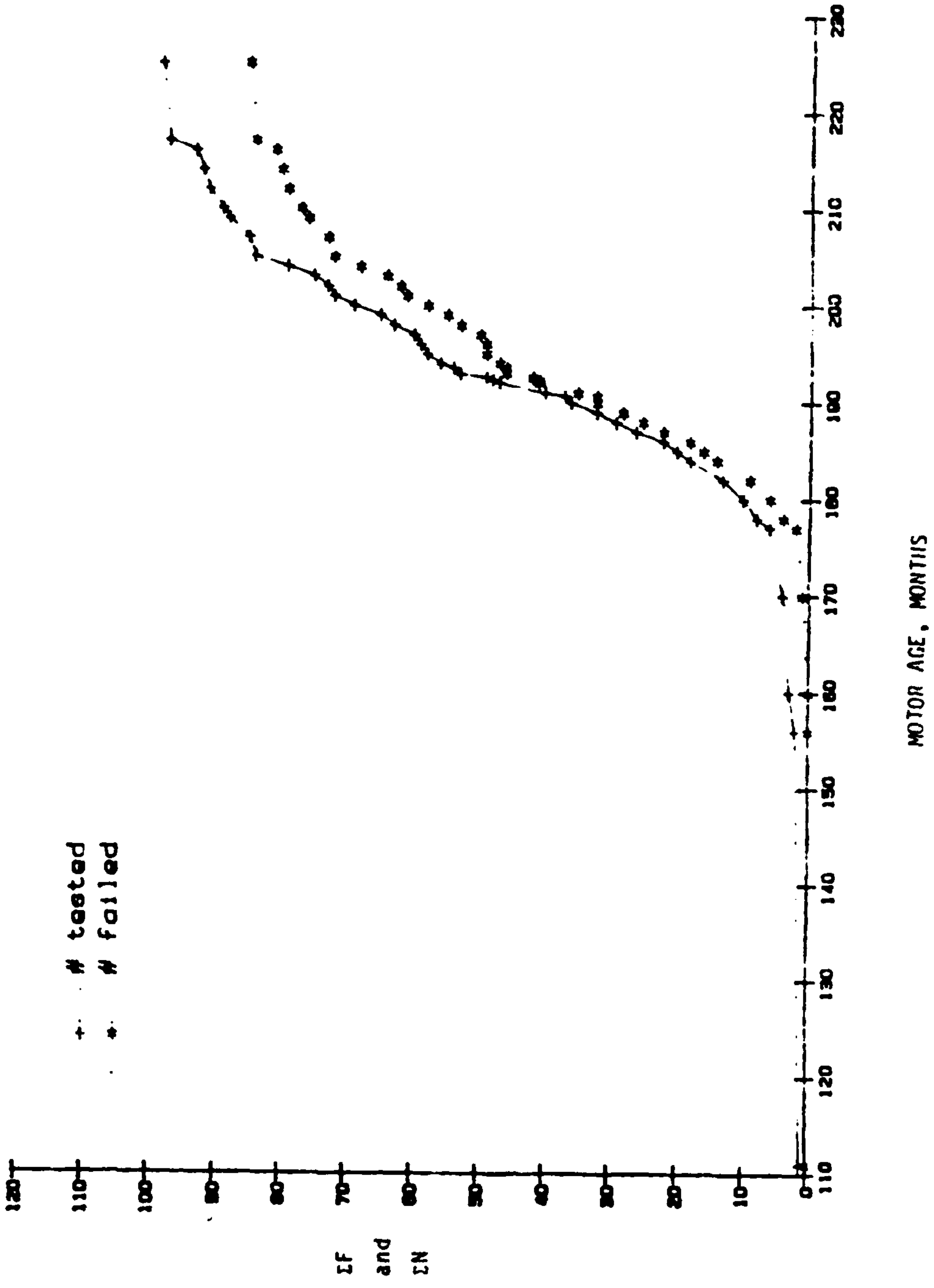


Figure D-2. Cumulative Distribution for Phillips

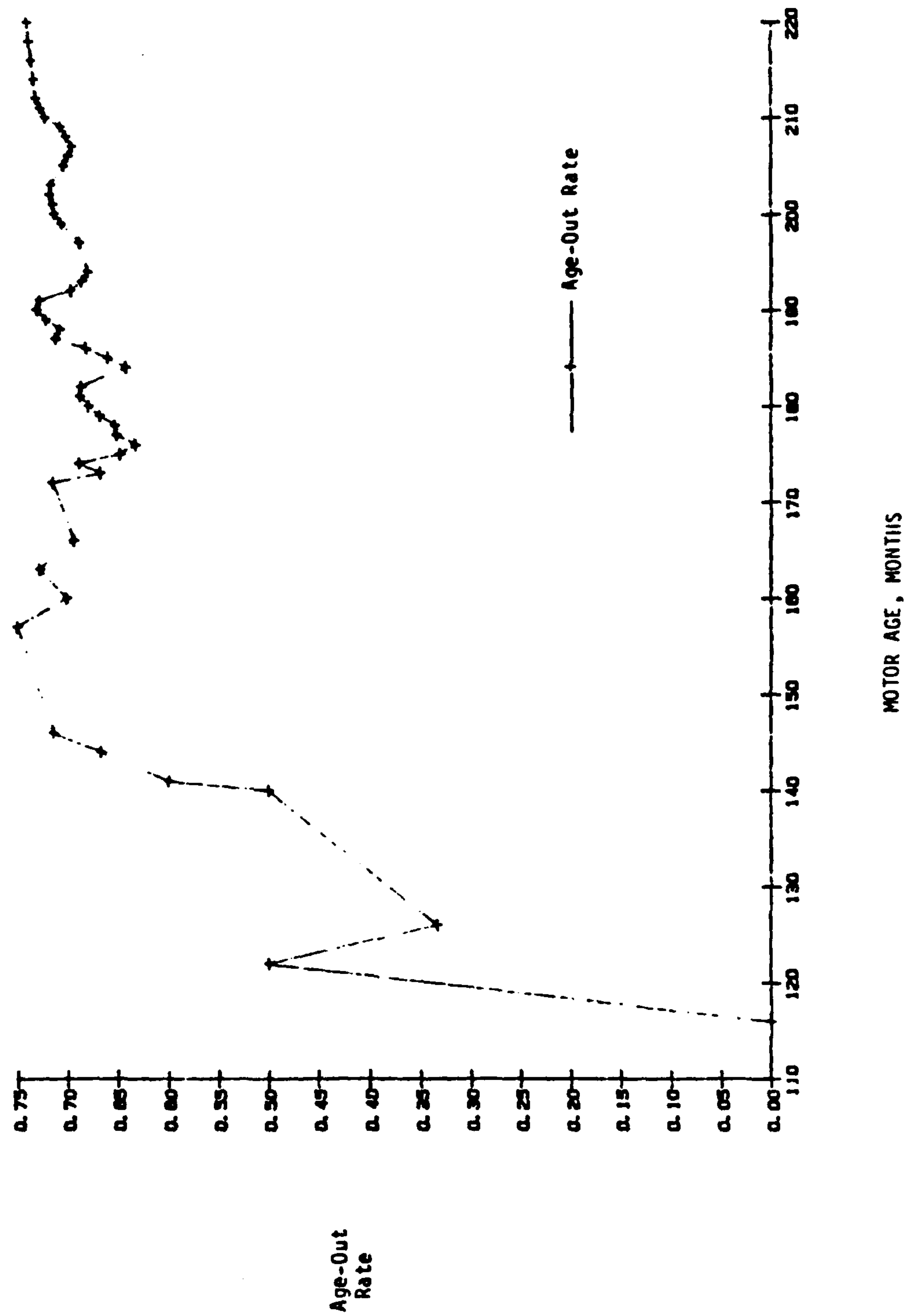


Figure D-3. Approximate Rate of Motor Age-Out for GT&R Polymer

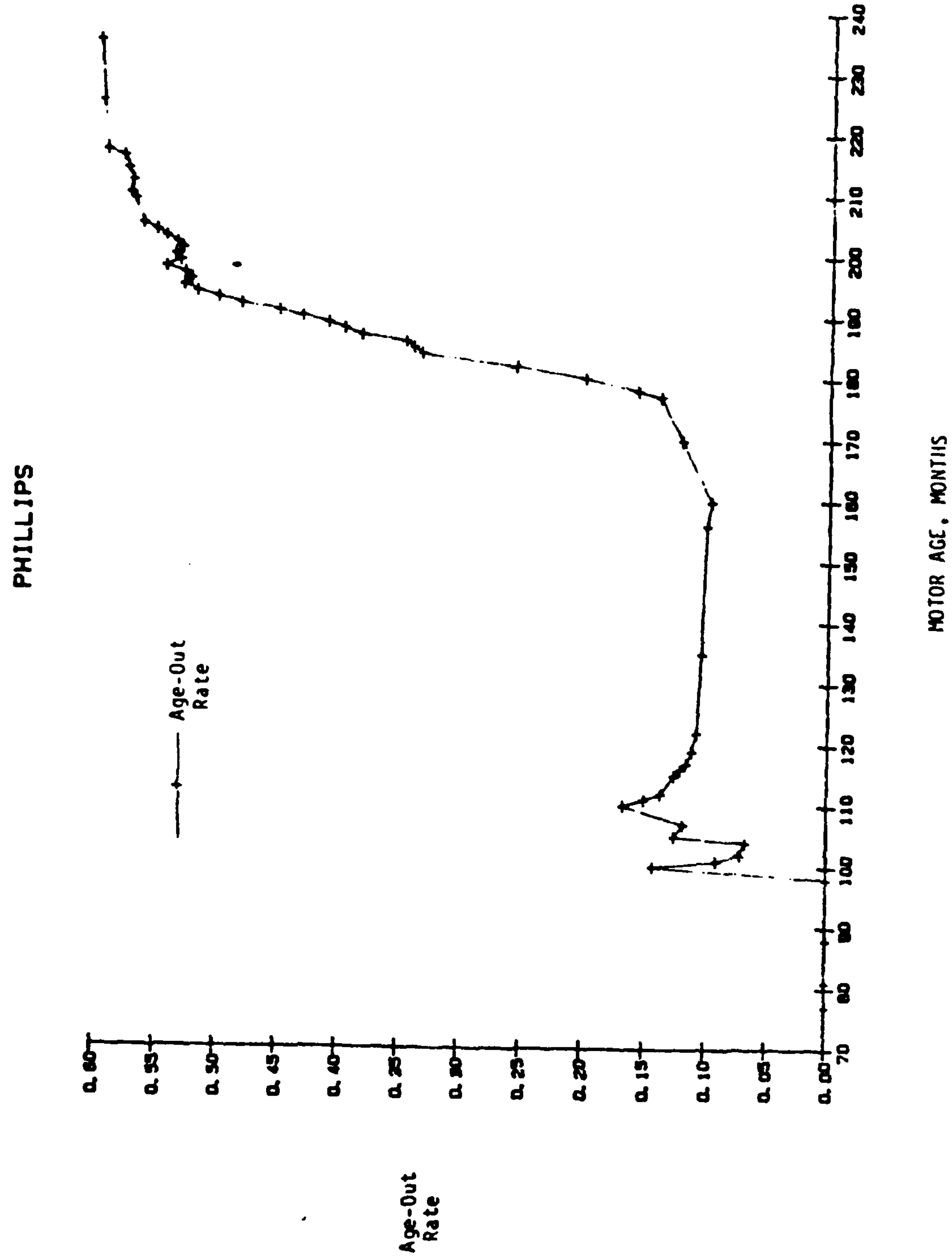


Figure D-4. Approximate Rate of Motor Age-Out for Phillips Polymer

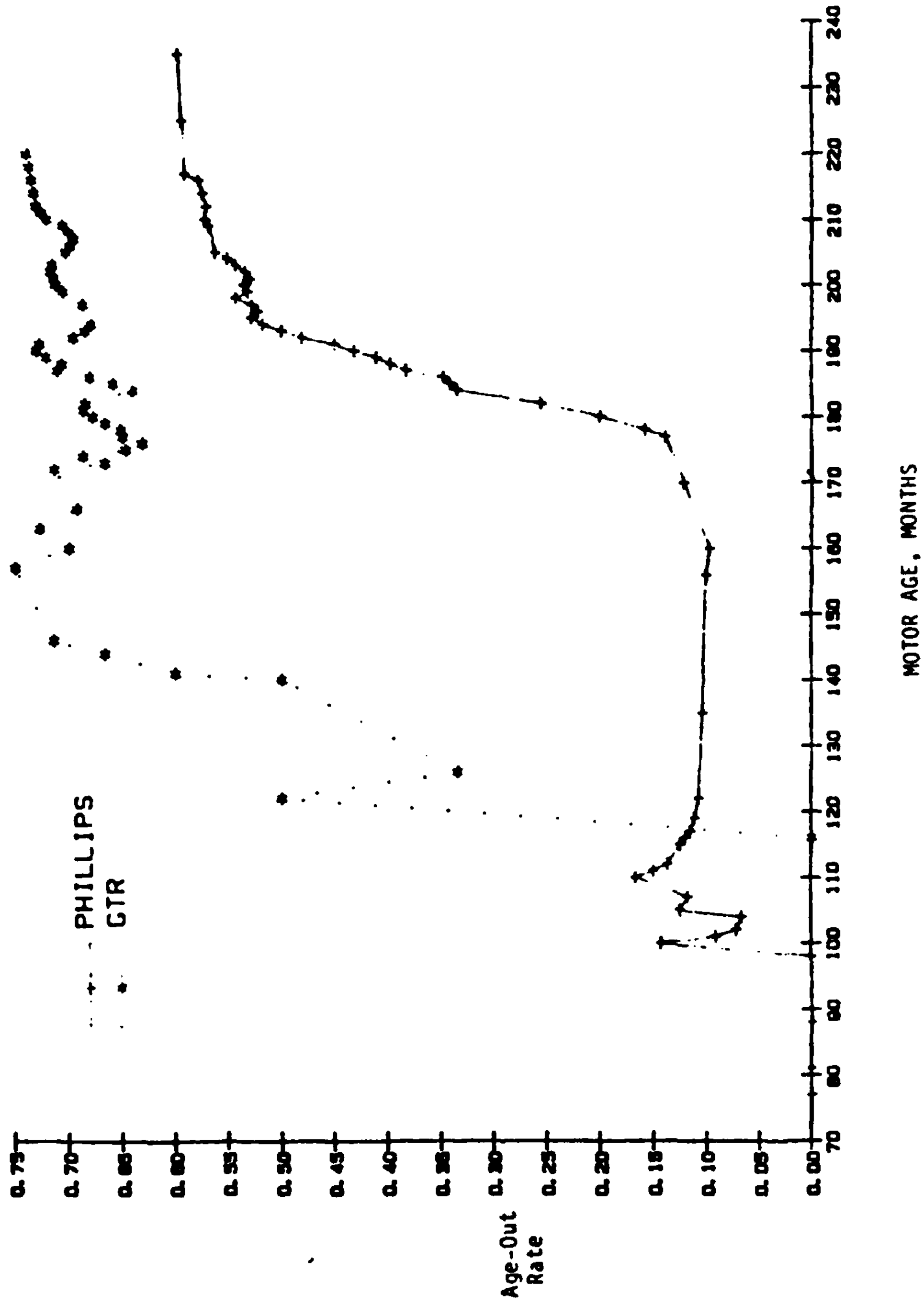


Figure D-5. Comparison of Motor Age-Out Rates for GT&R and Phillips Polymers in Forward Boot

II.A. Age-Out at the Forward Boot (Cont)

polymer tend to age longer (about 4 years). Both sets of data exhibit a flattened portion of the curve at long times with the GT&R polymer giving an age-out rate between 0.70 and 0.75, while the motors using the Phillips polymer have a maximum rate below 0.60.

A word of caution should be given at this point. These curves actually fall to the right (greater aging times) of the curves that would be generated at the ages when the motors just equalled the age-out criterion. Also, the maximum rate should be asymptotic to 1.00. That asymptote is not indicated by these data because of the sampling technique which gives a bias to the results.

B. AGE-OUT AT THE AFT BOOT

Using the age-out criterion given for the forward boot, and possessing fewer data points, the analyses for the aft boot gave the simple results of Figure D-6. The early age-out rates for the GT&R polymer are attributed to a paucity of data at those times.

Both polymers produced curves which quickly attained a constant rate of age-out. The Phillips polymer reached an age-out rate of about 0.85 which is significantly greater than that for the GT&R polymer, about 0.72.

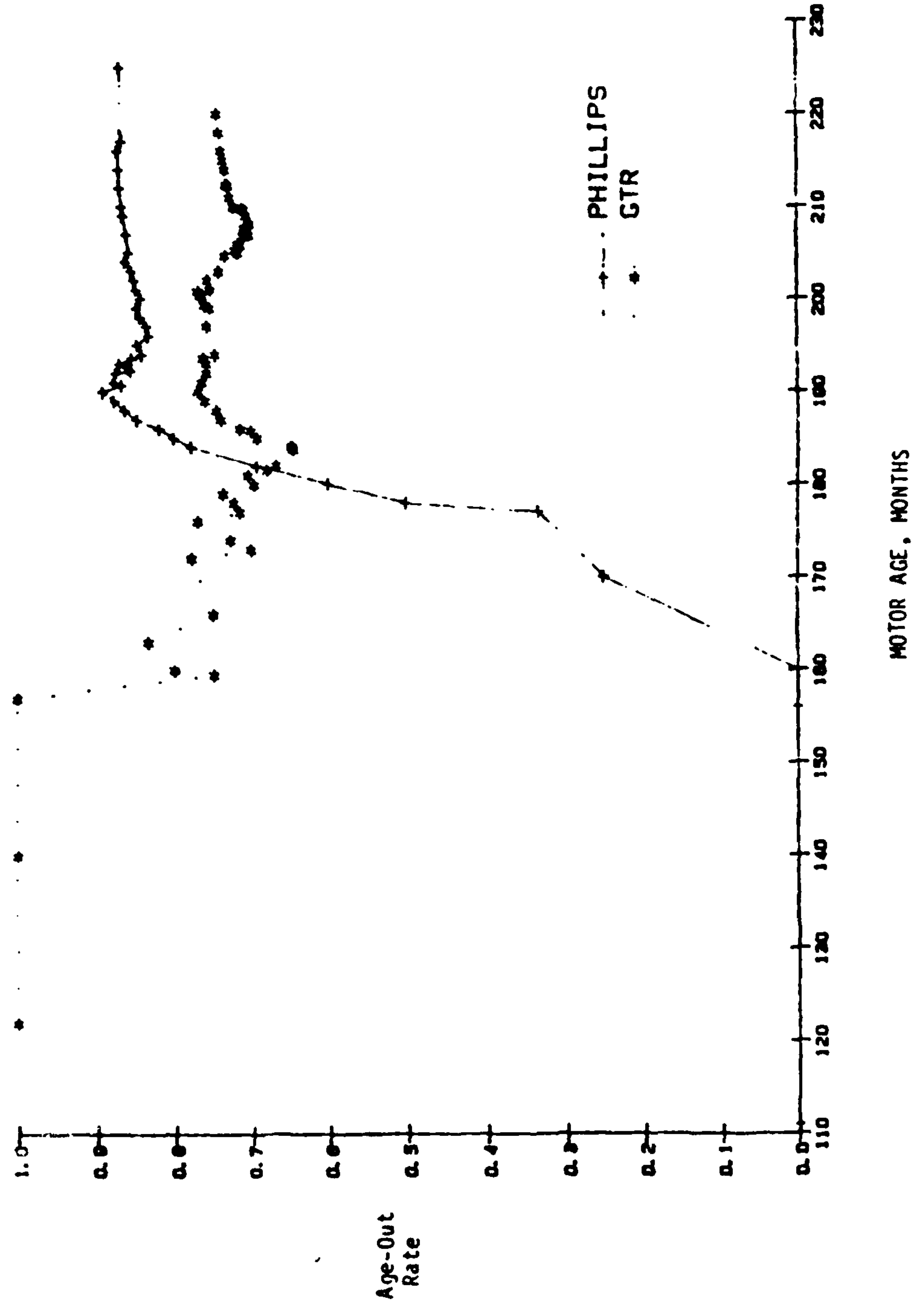


Figure D-6. Comparison of Motor Age-Out Rates for GT&R and Phillips Polymers in Aft Boot

III. RELATION OF NIPPLE-PROPELLANT GAP TO PROPERTY AND AGING VARIABLES

The following was a preliminary effort designed to correlate available motor test data with nipple-propellant gap measurements. The purpose of the correlation equation is to predict rates of motor age-out, an example of which is discussed in the following section.

A large database was available for this study, see Reference (a). These data included the manufacturing variables for the SD-851-2 liner for 1,347 Minuteman Second Stage production motors and 206 Third Stage production motors. In addition, excised sample data were obtained on 50 motors that ranged in age from 44 to 130 months. In all, 67 variables were collected for each motor.

The studies reported in Reference 12 were centered on the propellant-liner-boot bond strength as a function of age. For the present preliminary study, the significant variables in that study were accepted for consideration in this one. This assumption greatly reduced the effort of the current work. The parameters considered were C_2, C_{11}, C_{25}, C_{29}, C_{42}, C_{47}, and C_{48}, using the column code notation given in Reference (a). The descriptions of these variables are given in Table I.

The evaluation of these variables involved the statistical assessment of the following 36 term equation:

$$\begin{aligned} \text{Gap} = {} & A_0 + A_1 C_2 + A_2 C_{11} + A_3 C_{25} + A_4 C_{29} + A_5 C_{42} + A_6 C_{47} + \\ & A_7 C_{48} + A_8 C_2^2 + A_9 C_{11}^2 + A_{10} C_{29}^2 + A_{12} C_{42}^2 + \\ & A_{13} C_{47}^2 + A_{14} C_{48}^2 + A_{15} C_2 C_{11} + A_{16} C_2 C_{25} + A_{17} C_2 C_{29} + \\ & A_{18} C_2 C_{42} + A_{19} C_2 C_{47} + A_{20} C_2 C_{48} + A_{21} C_{11} C_{25} + \\ & A_{22} C_{11} C_{29} + A_{23} C_{11} C_{42} + A_{24} C_{11} C_{47} + A_{25} C_{11} C_{48} + \\ & A_{26} C_{25} C_{29} + A_{27} C_{25} C_{42} + A_{28} C_{25} C_{47} + A_{29} C_{25} C_{48} + \\ & A_{30} C_{29} C_{42} + A_{31} C_{29} C_{47} + A_{32} C_{29} C_{48} + A_{33} C_{42} C_{47} + \\ & A_{34} C_{42} C_{48} + A_{35} C_{47} C_{48} \end{aligned} \tag{2}$$

Where the A_i are constants.

III. Relation of Nipple-Propellant Gap to Property and Aging Variables (Cont)

TABLE 1. MANUFACTURING VARIABLES AND CODES FOR DATA LISTING OF 50 EXCISED MOTORS

Column Code	Variable
C_2	Bond Tensile Strength (DPT) - From Motor Sample Carton, psi
C_{11}	Premix Moisture Content, Weight Percent
C_{25}	Delta Viscosity Buildup, Poise
C_{29}	Liner Accelerated Cure, Rex Hardness
C_{42}	Insulation Water, %
C_{47}	Liner Swelling Ratio Transform $[1000/S_e/S_o)^5]$
C_{48}	Motor Age, Months

This preliminary assessment was limited to the motor with the GT&R polymer, since they produced the earliest overall age-out. The motors with GT&R polymer, measured gap data, and excised sample testing, were a limited population of ten. Because of this small sample size, the assessment of Equation (2) had to be broken into parts with over 1500 multiple linear regression analyses being performed. The optimized regression equation was found to be

$$\begin{aligned} \text{Gap} = {} & 2.732 \times 10^{-1} - 1.39 \times 10^{-4}\, C_2\, C_{47} - 3.934 \times 10^{-2}\, C_{11}\, C_{47} + \\ & 8.635 \times 10^{-3}\, C_{11}\, C_{48} - 2.28 \times 10^{-4}\, C_{29}^2 - 7.834 \times 10^{-3}\, C_{29}\, C_{42} + \\ & 6.79 \times 10^{-4}\, C_{29}\, C_{47} + 7.9 \times 10^{-5}\, C_{29}\, C_{48} + 6 \times 10^{-6}\, C_{47}^2 \end{aligned} \tag{3}$$

III. Relation of Nipple-Propellant Gap to Property and Aging Variables (Cont)

It was found, however, that C_{42} and C_{47} were not available as a function of motor age (C_{48}). So, using the data from 31 aged motors with GT&R polymer and having excised sample data, the following linear regressions were found

$$C_{42} = 2.282 \times 10^{-3} C_{48} + 1.670 \quad (4)$$

$$C_{47} = - 2.297 \times 10^{-1} C_{48} + 5.691 \times 10^{1} \quad (5)$$

Combining Equations (3), (4) and (5) gives the final relationship.

$$\begin{aligned} Gap = {} & 3.17 \times 10^{-7} C_{48}^{2} + C_{48} [- 1.57 \times 10^{-4} + 3.2 \times 10^{-5} C_{2} + \\ & -.74 \times 10^{-2} C_{11} - 9.5 \times 10^{-5} C_{29}] - 7.91 \times 10^{-3} C_{2} - 2.24 C_{11} + \\ & 2.93 \times 10^{-1} 2.56 \times 10^{-2} C_{29} - 2.28 \times 10^{-4} C_{29} + \end{aligned} \quad (6)$$

IV. PREDICTING THE RATES OF MOTOR AGE-OUT

The ultimate goal of these efforts is to use the developed relationships to predict the behavior of the overall motor population. At this stage the predictions apply (in a preliminary manner) only to the subpopulation of motors that use the GT&R polymer.

Taking Equation (6) and inserting the age-out criterion of 0.03 in. for the Gap gives a quadratic equation for motor age, C_{48}. This relation has the following form

$$C_{48}^2 + b\, C_{48} + c = 0 \tag{7}$$

Where

$$b = -4.95 \times 10^2 + 1.01 \times 10^2\, C_2 + 5.49 \times 10^4\, C_{11} - 3 \times 10^2\, C_{29} \tag{8}$$

$$c = 8.28 \times 10^5 - 2.50 \times 10^4\, C_2 - 7.07 \times 10^6\, C_{11} + 8.06 \times 10^4\, C_{29} - 7.19 \times 10^2\, C_{29}^2 \tag{9}$$

The calculation of motor age-out, given the required data, is accomplished upon determining the parameters b and c [using Equations (8) and (9), respectively], then solving for motor age (C_{48}) using the standard quadratic solution. The determined motor age is that time when the gap just meets the age-out criterion of 0.03 in.

An example calculation of this type was made using the 31 motor test data (GT&R polymer) previously mentioned. The resulting age-out predictions for each motor were ranked in ascending order of time-to-age-out. The fraction of the population, F(m), for the mth observation of n total motors is given by

$$F(m) = \frac{m}{n+1} \tag{10}$$

IV. Predicting the Rates of Motor Age-Out (Cont)

A plot of F(m) versus motor age is given in Figure D-7. The results represent a simple cumulative distribution curve as expected. In addition, the curve is compared with the previously presented motor measurement results. As expected, the predicted relation is earlier in time and falls asymptotic to the upper limit of 1.0.

Both curves would be shifted to longer times if an age-out criterion larger than 0.03 in. had been selected.

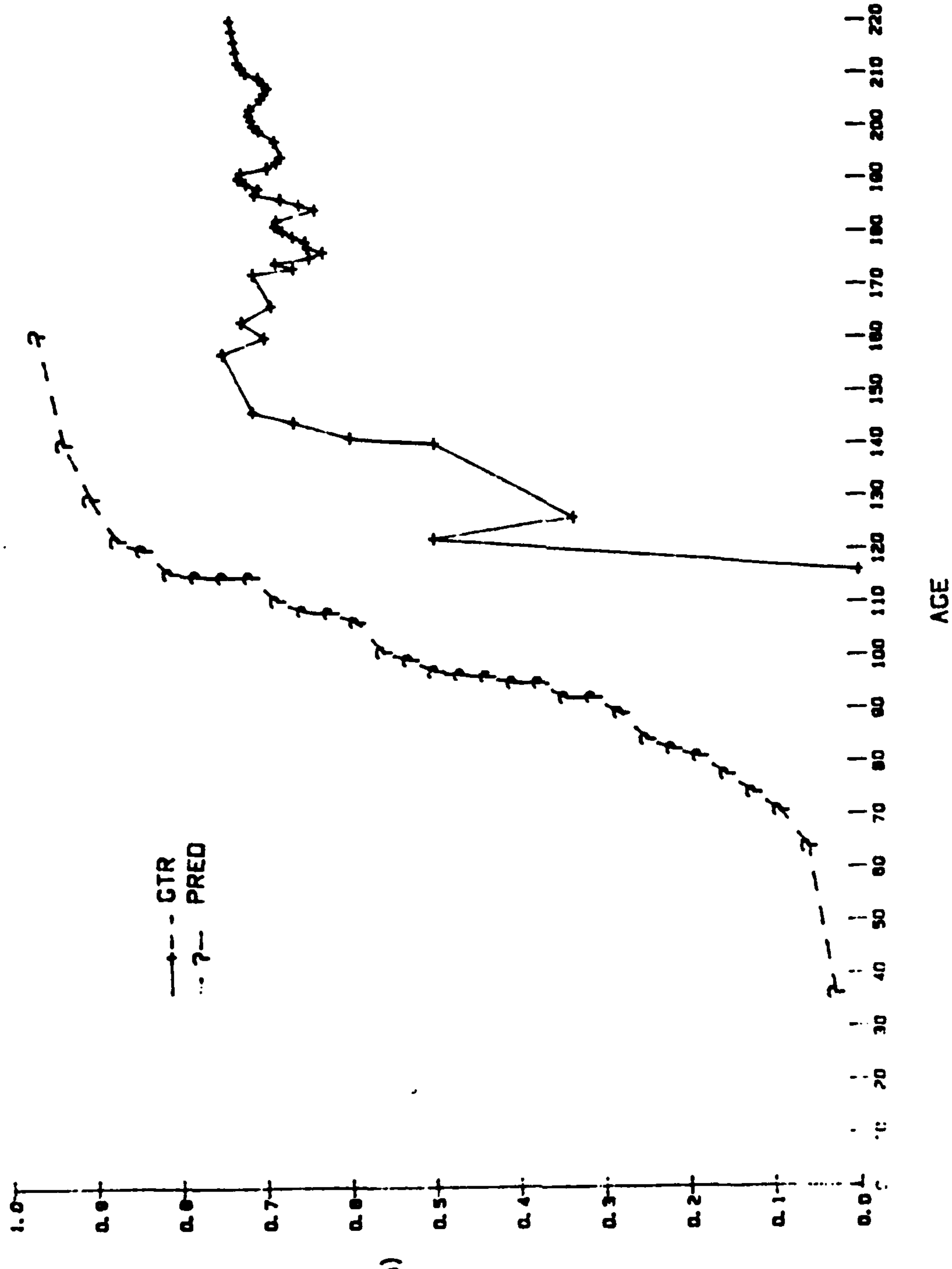


Figure D-7. Prediction of Motor Age-Out at the Forward Nipple of Motors With GT&R Polymer (Comparison With Observed Failure Rate Data)

V. CONCLUSIONS AND RECOMMENDATIONS

The motor age-out appears to be predictable from the type of test data taken in motor manufacturing, supplemented somewhat by motor excised sampling data. At least 10 more motors should be excised where gap measurements are known and covering a range of motor ages.

The age-out criterion should be reviewed, possibly using these analyses over a range of values.

The small grouping of early age-out motors for the Phillips polymer needs to be assessed further to account for some unique or overlooked conditions.

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